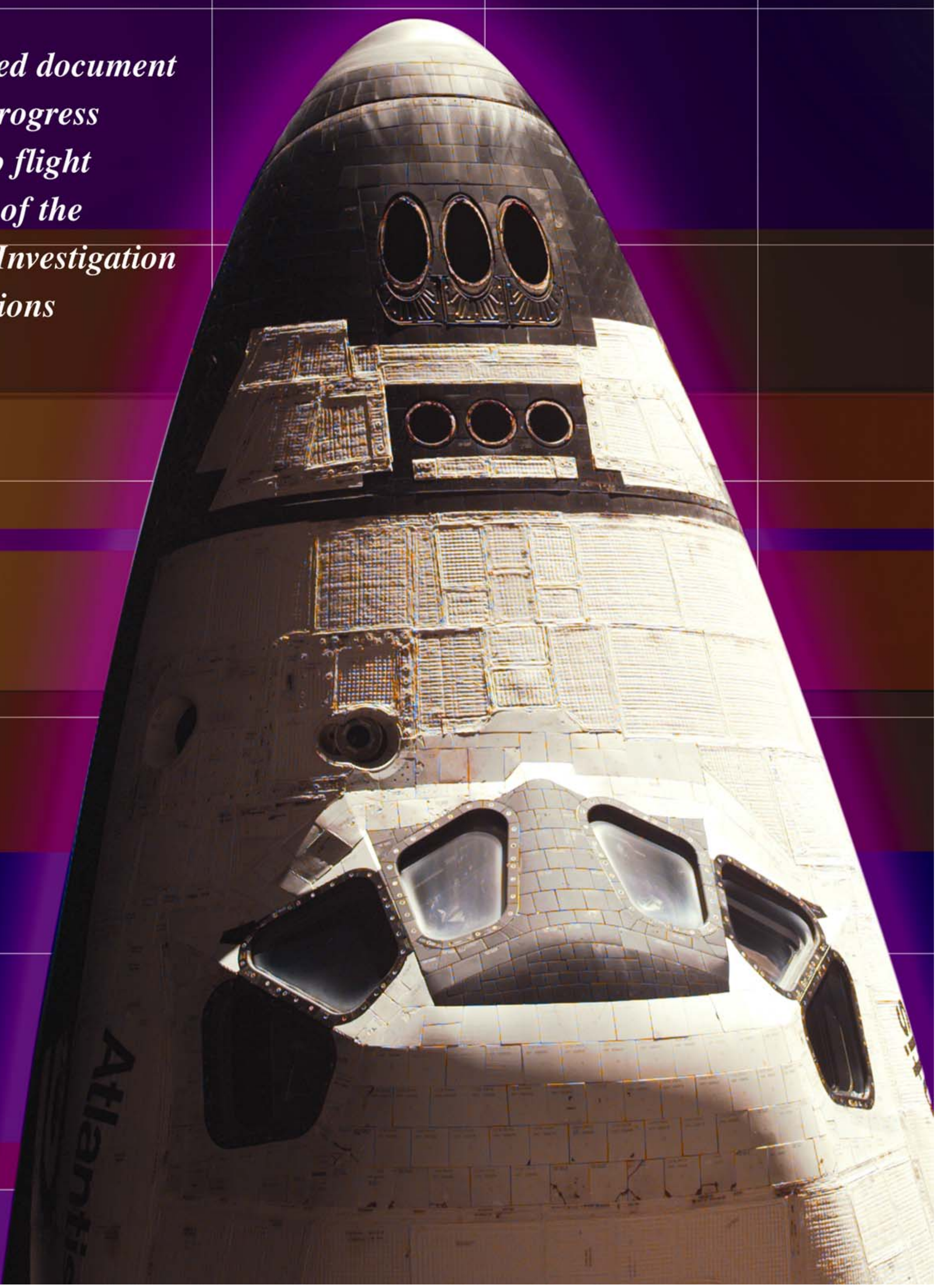
August 27, 2004
Volume 1, Revision 2.2

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond

A periodically updated document demonstrating our progress toward safe return to flight and implementation of the **Columbia** *Accident Investigation Board recommendations*



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An electronic version of this implementation plan is available at www.nasa.gov

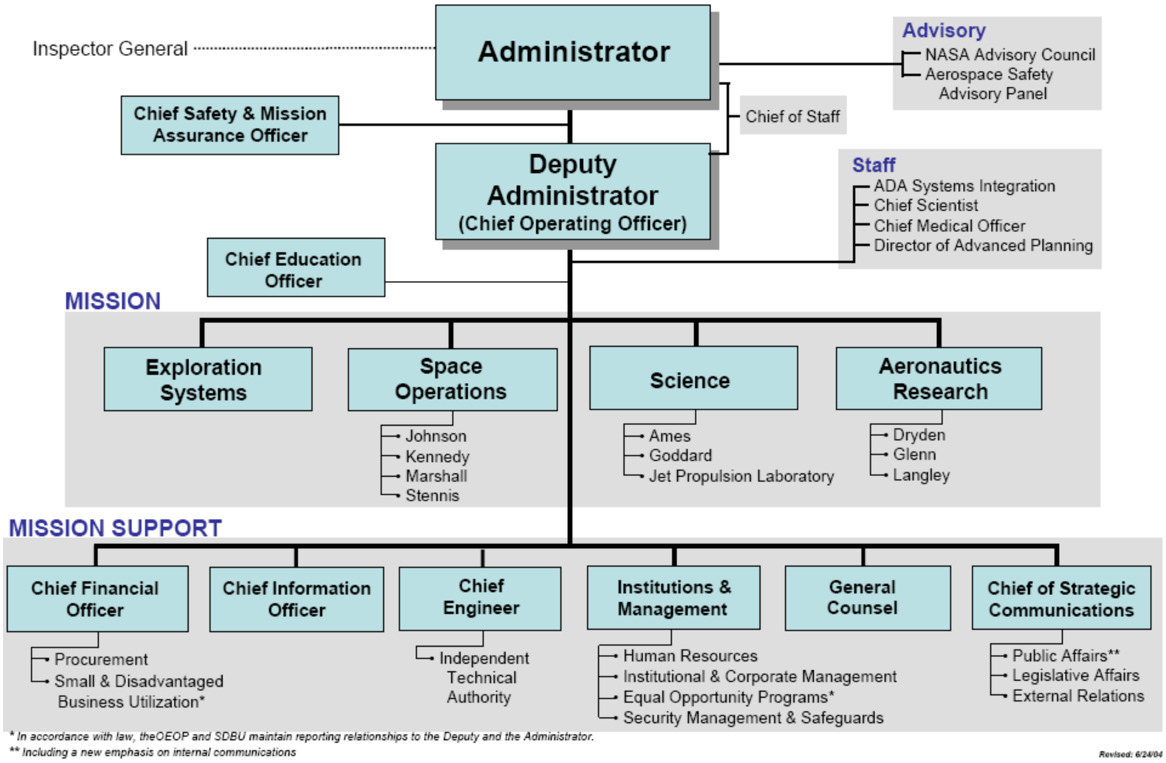
Revision 2.2 Summary
August 27, 2004

This revision to *NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond* updates several critical areas in our return to flight (RTF) efforts. Progress continues in our Thermal Protection System (TPS) impact testing and material analysis. These tests are helping NASA to refine our requirements for damage tolerance. Work is also ongoing to refine TPS repair materials and techniques. In addition, the Space Shuttle Program has approved the implementation of an enhanced, robust suite of ground imagery, on-vehicle imagery, and on-orbit imagery; these imagery assets will help us to gain important engineering insight into the Space Shuttle's performance, and particularly the performance of the redesigned External Tank (ET).

On August 1, 2004, the NASA Administrator appointed Admiral Walter Cantrell as the NASA Independent Technical Authority (ITA). This appointment was an important step in implementing the *Columbia* Accident Investigation Board (CAIB) ITA recommendation. ITA implementation plans are under development in each of the NASA Space Operations Centers, and in the Space Operations Mission Directorate. NASA is also nearing completion of the plan to address Recommendation 9.1-1 and the organizational causes of the *Columbia* accident.

On June 24, 2004, NASA announced a transformation of NASA's organizational structure designed to streamline the Agency and position us to better implement the Vision for Space Exploration. The President's Commission on Implementation of U.S. Space Exploration Policy found that "NASA needs to transform itself into a leaner, more focused agency by developing an organizational structure that recognizes the need for a more integrated approach to science requirements, management and implementation of systems development and exploration missions." The transformation restructured NASA's strategic Enterprises into Mission Offices, realigning those offices to better clarify organizational roles and responsibilities. In addition, we have clarified our relationship with the NASA Field Centers by developing clear and straightforward lines of responsibility and accountability. The Space Shuttle Program is in the Space Operations Mission Directorate under this new organizational structure, which includes the Office of Space Operations at NASA Headquarters and the four Field Centers that provide the fundamental support to the Shuttle Program: the Johnson Space Center, Kennedy Space Center, Marshall Space Flight Center, and Stennis Space Center.

These changes represent not only the next step in implementing the recommendations of the President's Commission on Implementation of U.S. Space Exploration Policy, but they also reflect NASA's ongoing efforts to apply the findings and recommendations of the CAIB across the Agency.



NASA has also made progress working with the Return to Flight Task Group (RTFTG) toward closing out the CAIB's RTF actions. NASA has conditionally closed five of the 15 RTF recommendations, including: Recommendations 3.3-1, Reinforced Carbon-Carbon Inspections; 4.2-3, Two-Person Closeouts; 6.3-2, National Assets; 4.2-5, Foreign Object Debris; and 10.3-1 Closeout Photography. The remaining RTF actions will be presented to the RFTG over the next several months. NASA's goal is to achieve closure on all 15 RTF recommendations by December 2004.

Following is a list of sections affected by this Revision:

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- 3.3-2 Orbiter Hardening [RTF]
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- 3.4-3 On-Vehicle Ascent Imagery [RTF]
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Return to Flight Message from the Space Flight Leadership Council

The past year has been a time of great change for NASA. In the one year since the release of the *Columbia* Accident Investigation Board (CAIB) Final Report, NASA has taken action to meet or exceed the Board's Return to Flight (RTF) recommendations, as well as to "raise the bar" with a number of self-generated related actions. In the process, we have fundamentally changed the way that we go about the business of human space flight, reexamining and re-vamping our engineering practices and culture. The Vision for Space Exploration, announced on January 14, 2004, outlined a "building block" strategy to explore destinations across the Solar System. The first steps of this vision are to safely return the Space Shuttle to flight, to complete the assembly of the International Space Station (ISS), and to focus Station research on supporting exploration goals. Following ISS assembly, the Shuttle will be retired.

To meet the challenges of the Vision for Space Exploration, NASA has undertaken a broad Transformation Initiative. On August 1, 2004, NASA implemented a significant organizational restructuring. As part of this transformation, Walter Cantrell has been appointed Co-chair of the Space Flight Leadership Council (SFLC) and as the Deputy Chief Engineer for Independent Technical Authority. He succeeds Dr. Michael Greenfield on the SFLC, whose technical leadership and wisdom aided in making key decisions and keeping NASA focused on safely returning to flight.

The recommendations, findings, and observations from the CAIB Report are providing a roadmap to safely and successfully resume the NASA journey into space. The CAIB Report reflects strong support for Space Shuttle return to flight "at the earliest date consistent with the overriding objective of safety." NASA has worked closely with the Stafford-Covey Return to Flight Task Group to reach agreement on compliance with five (5) of the Board's fifteen (15) RTF recommendations. Recommendations 3.3-1, 4.2-3, and 6.3-2 were conditionally closed at the April 2004 Task Group Plenary, followed by Recommendations 4.2-5 and 10.3-1 at the July 2004 Plenary. NASA is making measurable progress toward compliance with the re-maining RTF recommendations, completing the "raising the bar" actions, and meeting milestones necessary to support RTF in Spring 2005.

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond remains a living document that is continually updated with the latest plans and progress made in response to the CAIB Report and self-generated actions. Consistent with NASA's Transformation, all action plans accurately reflect the Vision for Space Exploration.

The STS-107 crew – Mike Anderson, David Brown, Kalpana Chawla, Laurel Clark, Rick Husband, Willie McCool, and Ilan Ramon – remain in our hearts and minds as we work to return to flight. Their legacy will continue to inspire us on the road ahead. In improving the safety of human space flight, we strive for excellence in all aspects of our work, including strengthening our culture and enhancing our technical capabilities. We remain dedicated to upholding the core values of Safety, the NASA Family, Excellence, and Integrity, in everything we do.

NASA will return to flight smarter, stronger, and safer!

Walter H. Cantrell

Walter H. Cantrell
Deputy Chief Engineer
for Independent Technical Authority

William Readdy

William F. Readdy
Associate Administrator
for Space Operations

NASA Space Shuttle Return to Flight (RTF) Suggestions

As part of NASA's response to the *Columbia* Accident Investigation Board (CAIB) recommendations, the Administrator asked that a process be put in place for NASA employees and the public to provide their ideas to help NASA safely return to flight. With the first public release of NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond on September 8, 2003, NASA created an electronic mailbox to receive RTF suggestions. The e-mail address is "RTFsuggestions@nasa.gov." A link to the e-mail address for RTF suggestions is posted under the return to flight link on the NASA Web page "www.nasa.gov."

The first e-mail suggestion was received on September 8, 2003. Since then, NASA has received a total of 2683 messages, averaging 56 messages per week. NASA has provided a personal reply to each message. When applicable, information was provided as to where the message was forwarded for further review and consideration.

As NASA approaches our planned RTF date, it is critical that we move from development to implementation. As a part of this effort, we are now baselining all critical RTF activities. As a result, although we will continue to maintain the RTFsuggestions@nasa.gov e-mail box, beginning on September 1, 2004, NASA addressees will receive an automated response. NASA will periodically review the suggestions received for future use. We appreciate all of the interest and thoughtful suggestions received to date and look forward to receiving many more suggestions to both improve the Space Shuttle system and apply to exploration systems.

Many of the messages received are provided for review to a Project or Element Office within the Space Shuttle Program, the International Space Station Program, the Safety and Mission Assurance Office, the Training and Leadership Development Office, the newly established NASA Engineering and Safety Center, or to the NASA Team formed to address the Agencywide implications of the CAIB Report for organization and culture.

NASA organizations receiving suggestions are asked to review the message and use the suggestion as appropriate in their RTF activities. When a suggestion is forwarded, the recipient is encouraged to contact the individual who submitted the suggestion for additional information to assure that the suggestion's intent is clearly understood.

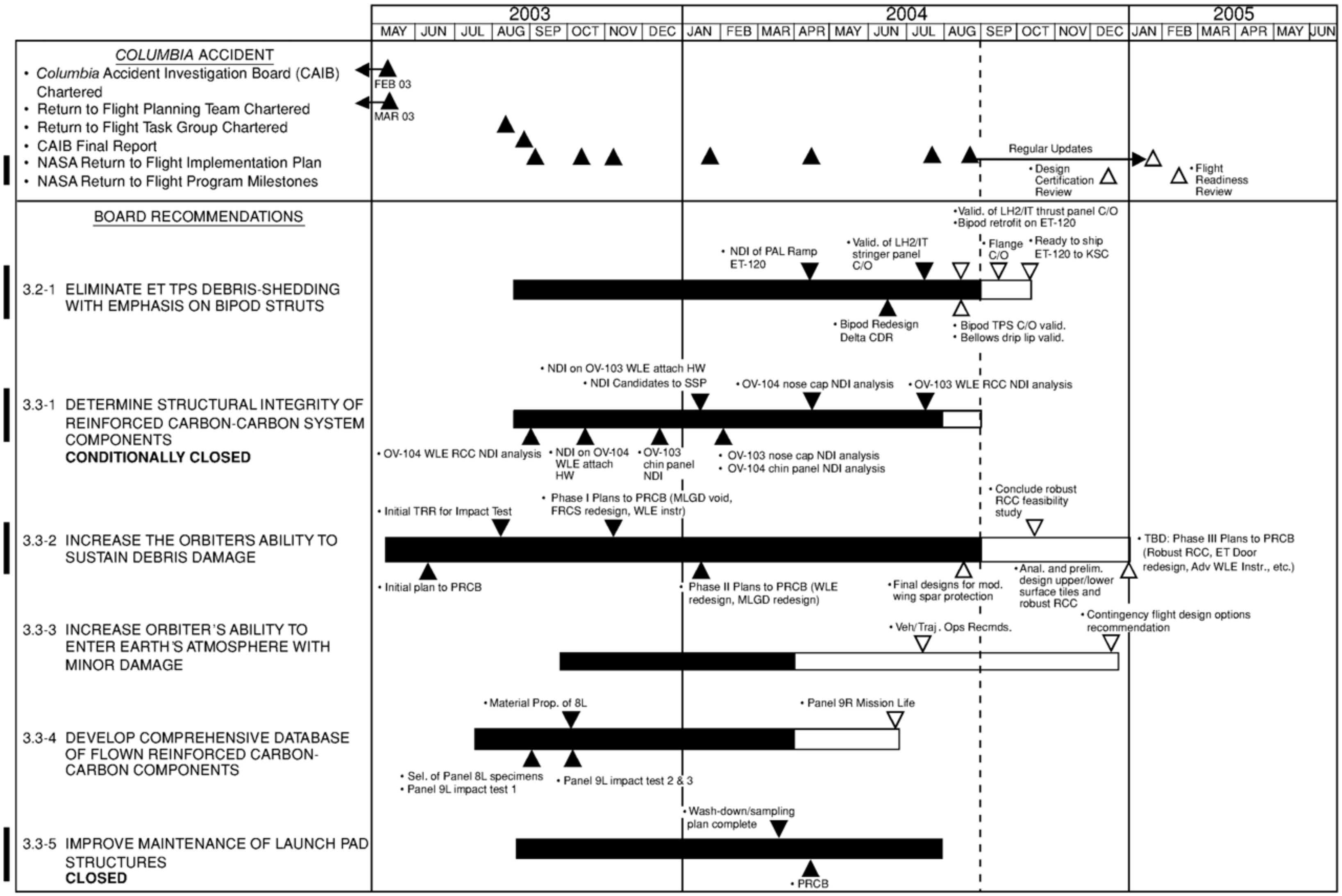
Table 1 provides a summary of the results. The table includes the following information: (1) the categories of suggestions; (2) the number of suggestions received per category; and (3) examples of RTF suggestion content from each category.

Synopsis of Return to Flight Suggestions

Category	No. of Suggestions	Example Suggestion Content
Orbiter	673	(1) Develop a redundant layer of Reinforced Carbon-Carbon panels on the Orbiter wing leading edge (WLE). (2) Cover the WLE with a titanium skin to protect it from debris during ascent.
External Tank	599	(1) Insulate the inside of the External Tank (ET) to eliminate the possibility of foam debris hitting the Orbiter. (2) Shrink wrap the ET to prevent foam from breaking loose.
General Space Shuttle Program	400	(1) Simulate Return to Launch Site scenarios. (2) Orbit a fuel tank to allow the Orbiter to refuel before entry and perform a slower entry. (3) Establish the ability to return the Shuttle without a crew on board.
Imagery/Inspection	183	(1) Use the same infrared imagery technology as the U.S. military to enable monitoring and tracking the Space Shuttle during night launches. (2) Use a remotely controlled robotic free-flyer to provide on-orbit inspection. (3) Bring back the Manned Maneuvering Unit to perform on-orbit inspection of the Orbiter.
Vision for Space Exploration	179	(1) Bring back the Saturn V launch vehicle to support going to the Moon and Mars. (2) Preposition supply/maintenance depots in orbit to reduce the need for frequently returning to Earth. (3) Construct future habitats and vehicles in space to eliminate launching large payloads from Earth.
Aerospace Technology	137	Quickly develop a short-term alternative to the Space Shuttle based on existing technology and past Apollo-type capsule designs.
Crew Rescue/Ops	127	(1) Implement a joint crew escape pod or individual escape pods within the Orbiter cockpit. (2) Have a second Shuttle ready for launch in case problems occur with the first Shuttle on orbit. (3) Have enough spacesuits available for all crewmembers to perform an emergency extravehicular activity.
Systems Integration	126	(1) Mount the Orbiter higher up on the ET to avoid debris hits during launch. (2) Incorporate temporary shielding between the Orbiter and ET that would fall away from the vehicle after lift off.
Public Affairs	85	NASA needs to dramatically increase media coverage to excite the public once again, to better convey the goals and challenges of human space flight, and to create more enthusiasm for a given mission.
NASA Culture	65	(1) Host a monthly employee forum for discussing ideas and concerns that would otherwise not be heard. (2) Senior leaders need to spend more time in the field to keep up with what is actually going on.
NASA Safety and Mission Assurance	47	(1) Learn from the Naval Nuclear Reactors Program. (2) The Government Mandatory Inspection Point review should not be limited to just the Michoud Assembly Facility and Kennedy Space Center elements of the Program.
Space Shuttle Program Safety	27	(1) Develop new Solid Rocket Boosters (SRBs) that can be thrust-controlled to provide a safer, more controllable launch. (2) Use rewards and incentives to promote the benefits of reliability and demonstrate the costs of failure.
International Space Station	20	(1) Adapt an expandable rocket booster to launch Multi-Purpose Logistics Modules to the International Space Station (ISS). (2) Add ion engines to the ISS to give it extra propulsion capability.
Leadership and Management	9	(1) Employees need to be trained while still in their current job to prepare them for increasing positions of responsibility. (2) Institute a rotational policy for senior management, similar to that of the U.S. Armed Forces.

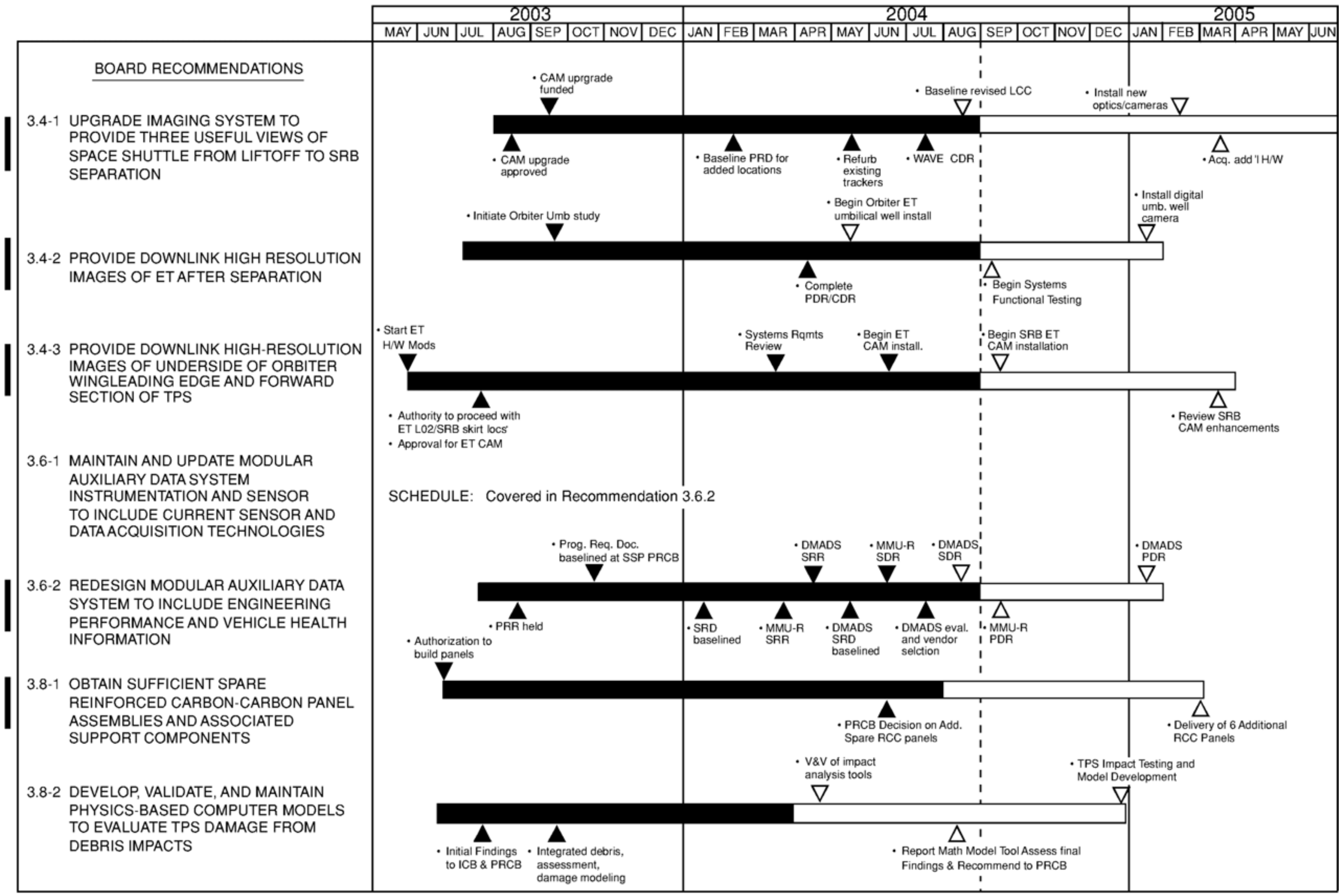
Category	No. of Suggestions	Example Suggestion Content
NASA Engineering and Safety Center	5	(1) Use a group brainstorming approach to aid in identifying how systems might fail. (2) NESC needs to get involved during a project's start as well as during its mission operations.
Solid Rocket Boosters	1	Ensure that the SRB hold-down bolts are properly reevaluated.
Total (As of August 9, 2004)	2683	

CAIB Recommendations Implementation Schedule



NOTE: See legend on p. xxv for definitions of acronyms

CAIB Recommendations Implementation Schedule



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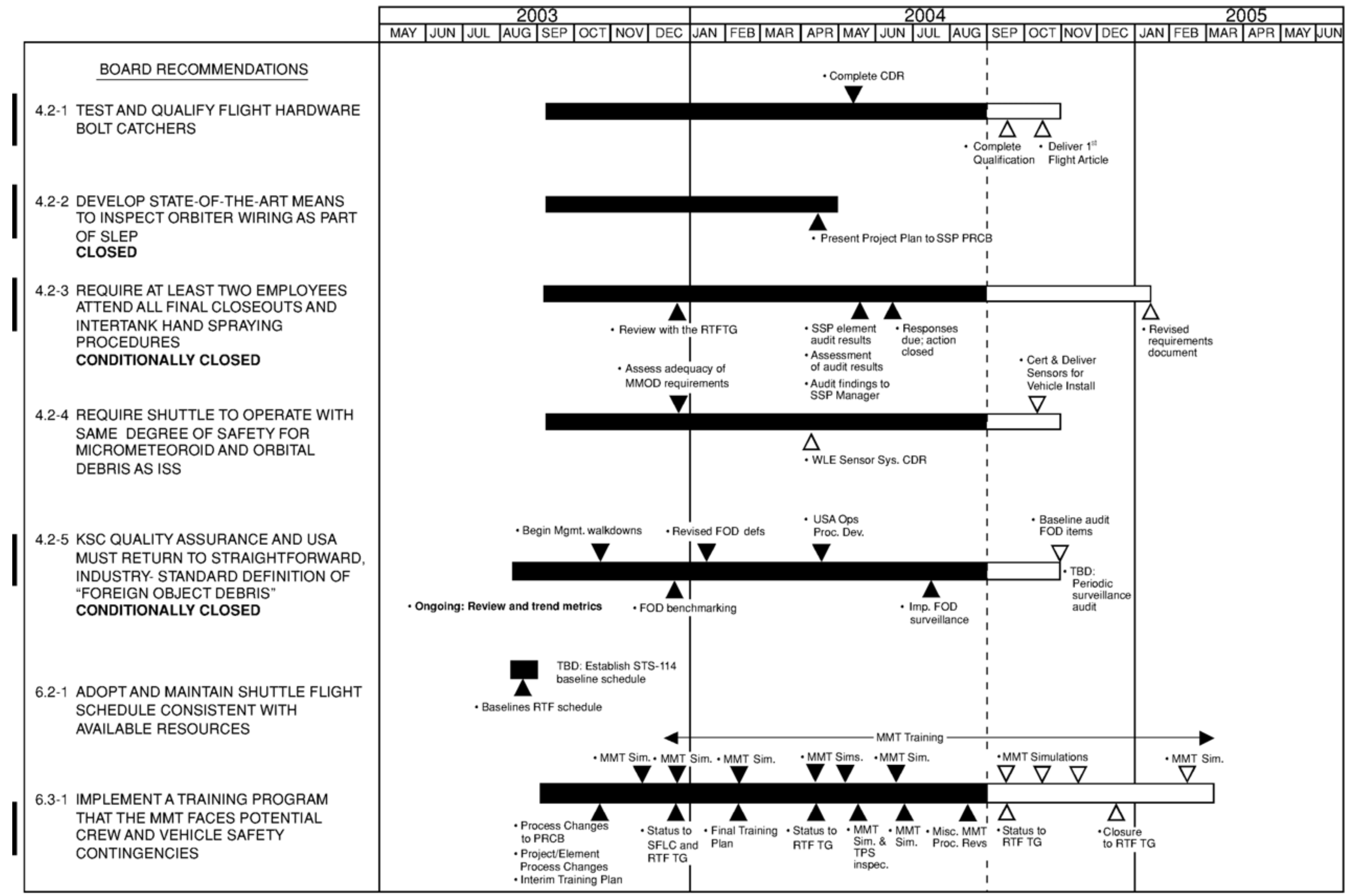
CAIB Recommendations Implementation Schedule



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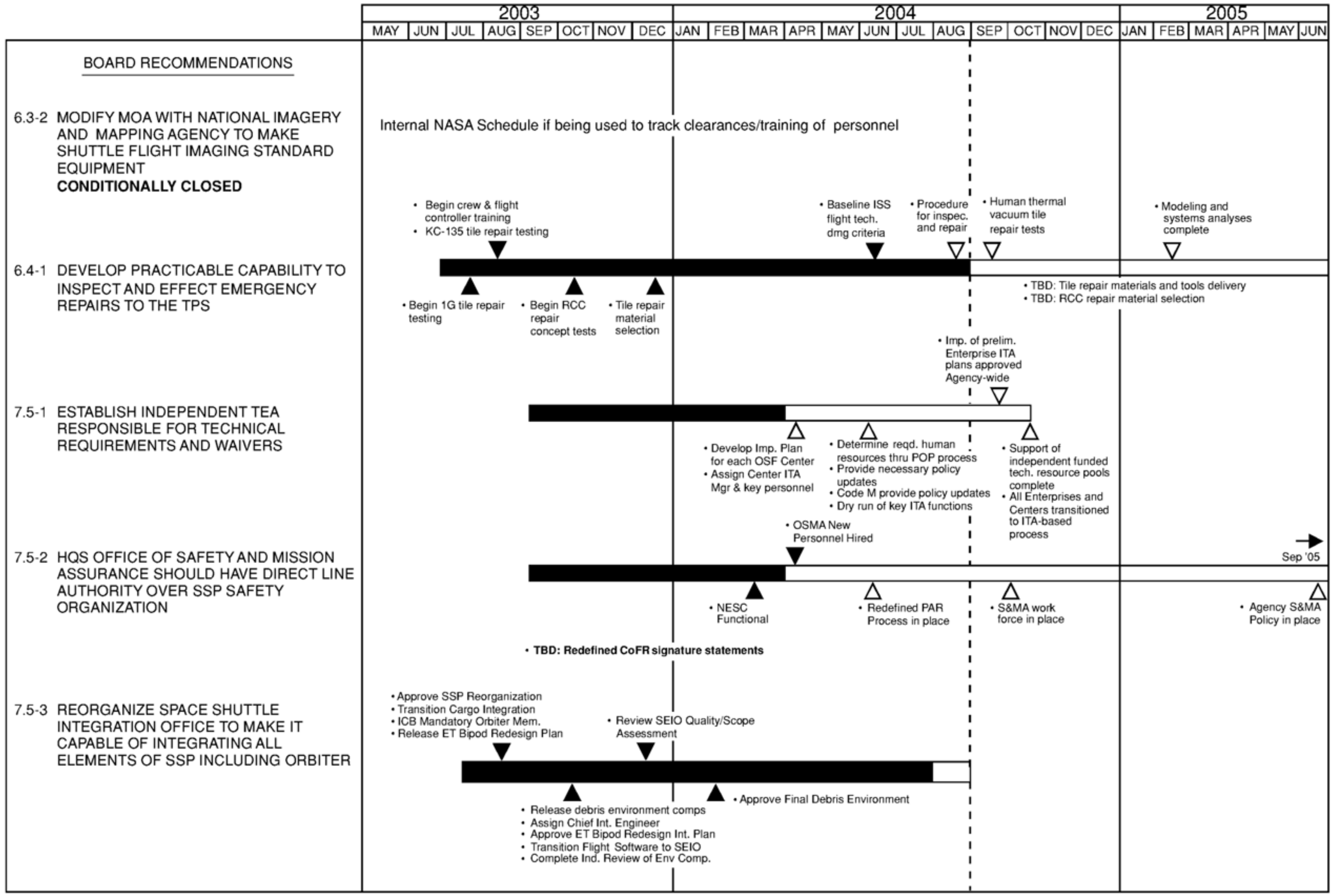
CAIB Recommendations Implementation Schedule



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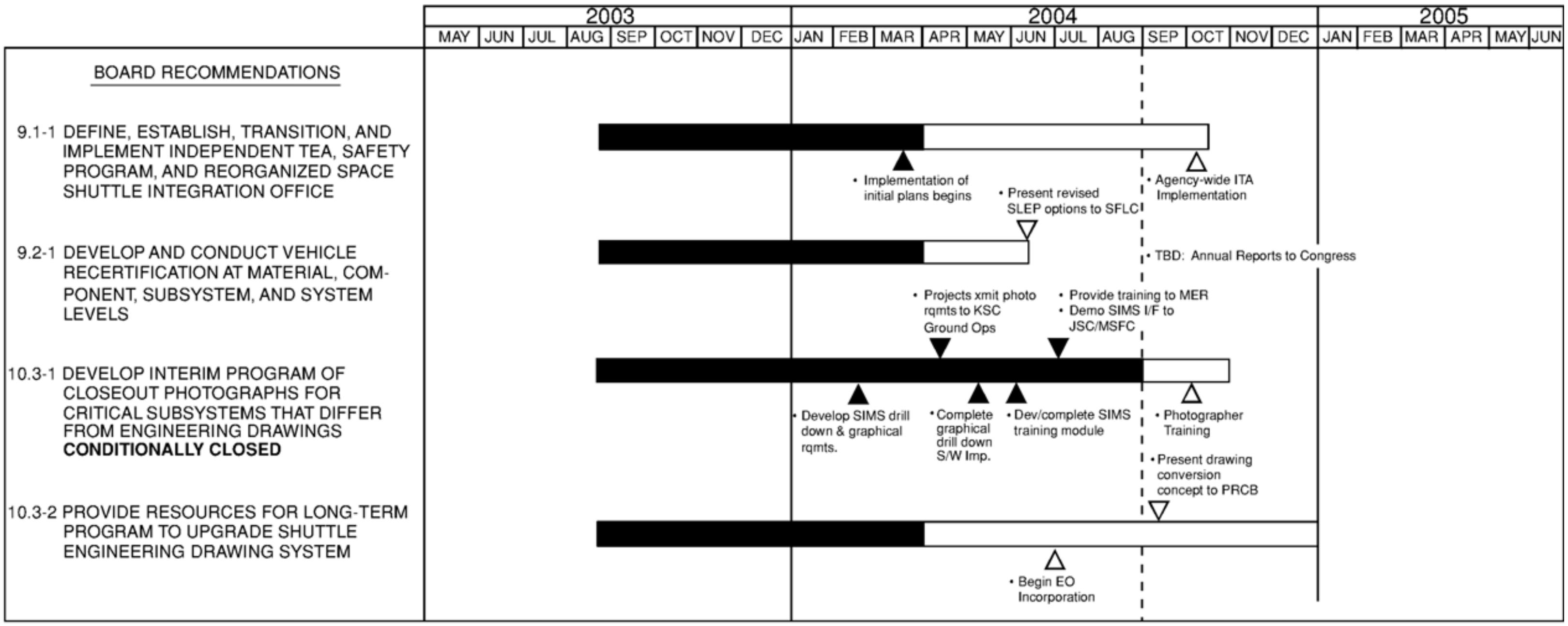


LEGEND

C/O – Closeout
CAM – Camera
CDR – Critical Design Review
DMADS – Digital Modular Auxiliary Data System
EO – Engineering Order
ET – External Tank
FOD – Foreign Object Debris
FRCS – Forward Reaction Control System
H/W – Hardware
I/F – Interface
ICB – Integration Control Board
ISS – International Space Station
IT – Intertank
ITA – Independent Technical Authority
KSC – Kennedy Space Center
LCC – Launch Commit Criteria
LH2 – Liquid Hydrogen
LO2 – Liquid Oxygen
MER – Mission Evaluation Room
MLGD – Main Landing Gear Doors
MMOD – Micrometeoroid/Orbital Debris
MMT – Mission Management Team
MMU-R – Mass Memory Unit-Retrofit
MOA – Memorandum of Agreement
MSFC – Marshall Space Flight Center
NESC – NASA Engineering and Safety Center
NDI – Nondestructive Inspection
OPS – Operations
OSF – Office of Space Flight
OSMA – Office of Safety and Mission Assurance
OV – Orbiter Vehicle
PAL – Protuberance Airload
PAR – Pre-Launch Assessment Review
PDR – Preliminary Design Review
PRD – Program Requirements Document
POP – Program Operating Plan
PRCB – Program Requirements Control Board
RCC – Reinforced Carbon-Carbon
RTFTG – Return to Flight Task Group
S/W – Software
S&MA – Safety and Mission Assurance
SEIO – Systems Engineering and Integration Office
SFLC – Space Flight Leadership Council
SIM – Simulation
SIMS – Still Imagery Management System
SLEP – Service Life Extension Program
SRB – Solid Rocket Booster
SRD – Systems Requirements Document
SRR – Systems Requirements Review
SSP – Space Shuttle Program
TEA – Technical Engineering Authority
TPS – Thermal Protection System
TRR – Test Readiness Review
UMB – Umbilical
USA – United Space Alliance
V&V – Verification and Validation
WAD – Work Authorization Document
WAVE – WB-57 Ascent Video Experiment
WLE – Wing Leading Edge

Return to Flight Cost Summary

Acting on preliminary *Columbia* Accident and Investigation Board (CAIB) recommendations and internal Space Shuttle Program (SSP) initiatives, NASA began incurring costs for return to flight (RTF) activities in fiscal year (FY) 2003. Initial cost estimates were based on RTF plans still in formulation and showed that NASA could need up to $94M in additional budget authority in FY 2003 and $265M in FY 2004. In response, NASA reprogrammed $43M from the Shuttle Service Life Extension Program and requested $50M in supplemental funding from Congress for *Columbia*-related activities. As FY 2003 came to a close, it became apparent that a large portion of the planned RTF work and associated costs would carry over into FY 2004, as the predicted launch date for the first mission back to the Space Station moved from the fall of 2004 to the spring of 2005. The Program entered FY 2004 with $533M in funding to carry over of which $139M was unencumbered and available to apply to RTF content.

At the start of FY 2004, NASA RTF plans were still evolving, and multiple paths were being investigated to provide the best technical response to the CAIB recommendations. The RTF budget estimates provided in FY 2003 were updated and the revised estimates were published in January 2004. NASA cautioned that since RTF content was still changing, the cost estimates for all years would also change. In its initial operating plan for FY 2004, NASA also noted that RTF engineering efforts were still dynamic and additional funds might be required to accommodate the changing RTF content before the end of the fiscal year. Through the second quarter of FY 2004, RTF technical efforts proceeded rapidly. Approval of specific RTF activities through the Shuttle Program Requirements Control Board (PRCB) meant that the maturity of the technical solutions was increasing, allowing for more accurate cost projections. All financial performance indicators showed that sufficient funds would be available to cover all critical path work in FY 2004, but that the costs for FY 2005 would likely exceed the FY 2005 budget requested for the Program. With a considerable amount of RTF work still to be reviewed and approved by the PRCB and the Space Flight Leadership Council and a potential for cost variations in the hundreds of millions of dollars, additional time will be required to assess funding needs for FY 2005 and beyond.

Through the third quarter of this fiscal year, RTF planning gave way to RTF execution and the Program came within the 12-month processing cycle for the first launch in 2005. In addition to the original RTF requirements, the *Columbia* experience led the Program to introduce a higher level of engineering and technical rigor. Many potential risks have been reevaluated and mitigated, resulting in a safer Shuttle system overall. Across the board, fight hardware is now subjected to greater levels of test, teardown, inspection, repair, and recertification for flight, and all elements of the Program are reassessing the adequacy of industrial processes, safety controls, integrated hazard analyses, and flight hardware test protocols. As a result, Program operations and sustaining engineering spending for FY 2004 and cost projections for FY 2005 have increased along with RTF costs.

As stated in the April 26 update to the Implementation Plan, earlier cost estimates did not include all RTF elements under consideration, additional requirements that may be derived from the continuing evaluation of the CAIB recommendations, costs incurred by other Agency activities in support of RTF, and Program budget reserve. This update takes into account all known potential costs, but does not include a budget reserve that could be needed to address unknown challenges that may arise after the first two flights in FY 2005. An integrated Program budget reserve approach will be addressed in the Agency's FY 2006 budget request. Table 1 shows current RTF/CAIB estimates through FY 2005.

The changes reflected on this page are corrections to typographical errors made during the publication process for Rev. 2.1. They do not reflect changes to the substance of the cost summary.

Table 1. Return to Flight Budget Estimates/Implementation Plan Map for New Estimates Including Threats* **As of July 21, 2004**

		(Cost in Millions)			Recommendation Numbers Map to Implementation Plan																													
		FY 03	FY 04	FY05**	CAIB #3.2-1	CAIB #3.3-1	CAIB #3.3-2	CAIB #3.3-3	CAIB #3.3-4	CAIB #3.3-5	CAIB #3.4-1	CAIB #3.4-2	CAIB #3.4-3	CAIB #3.6-1	CAIB #3.6-2	CAIB #3.8-1	CAIB #3.8-2	CAIB #4.2-1	CAIB #4.2-2	CAIB #4.2-3	CAIB #4.2-4	CAIB #4.2-5	CAIB #6.2-1	CAIB #6.3-1	CAIB #6.3-2	CAIB #6.4-1	CAIB #7.5-1	CAIB #7.5-2	CAIB #7.5-3	CAIB #9.1-1	CAIB #9.2-1	CAIB #10.3-1	CAIB #10.3-2	SSP Recommendation
(1)	**Total Initiated SSP RTF Activities**	**42**	**465**	**643**																														
RE/RP	Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares	2	38	7		X	X									X										X								
RE/RP	On-orbit TPS Inspection & EVA Tile Repair	20	68	130								X														X								X
AC	Orbiter Workforce	0	5	37																			X						X					X
RE/RP	Orbiter TPS Hardening	0	28	34			X																											
AC	Orbiter/GFE		7	4																														
AC	Orbiter Contingency		8	12																														
RE/RP	Orbiter Certification / Verification	0	47	26		X		X	X										X				X								X			X
RE/RP	External Tank Items (Camera, Bipod Ramp, etc.)	11	114	94	X								X							X														
RE/RP	SRB Items (Bolt Catcher, ETA Ring Invest., Camera)	1	8	26					X				X					X																X
RE/RP	Ground Camera Ascent Imagery Upgrade	8	40	58							X								X	X						X								
AC/RE	KSC Ground Operations Workforce		32	36						X									X	X						X								X
RE/RP	Other (System Intgr. JBOSC Sys, SSME Tech Assess)	0	67	177		X	X	X	X																		X	X	X	X				X
RE/RP	Stafford - Covey Team	0	3	1																														X
		(2)	(3)																															
	Other RTF Related* **																																	
	NASA Engineering and Safety Center (NESC)		45	77																								X	X	X				

RE = Reestimated Item; RP = Rephased; AC = Added Content

(1) The "Total SSP RTF Activities" budget line identified above represents an update to the estimates reflected in NASA's letters to the committees dated January 30, 2004. This update includes added scope of work and improved estimates. Although there is a greater level of technical maturity, requirements are still evolving, and cost estimates for those activities are dynamic and are still under evaluation to confirm the estimated cost and associated out-year phasing. Congress will be kept informed as we refine these requirements and associated cost estimates.
(2) In the last RTF update, NASA assumed an estimate of $94M in budget authority for FY 2003 could be needed. Since that time it became apparent that $52M of FY 2003 planned work and associated cost were carried into FY 2004.
(3) The updated FY 2004 RTF cost estimate of $465M includes $319M of activities that have been approved for implementation. The remaining $146M of RTF activities are pending approval. As soon as these additional activities are definitized, they will be shared with Congress.
*These estimates could change due to improved estimates, additional tasks, and added scope as we better understand the implementation of RTF recommendations.
**Cost estimates for FY 2005 and beyond will be refined as the Program comes to closure on RTF technical solutions and the RTF plan is finalized.
***The NASA Engineering and Safety Center (NESC) is funded through NASA's Corporate G&A. The NESC at NASA's Langley Research Center in Hampton, Va., provides comprehensive examination of all NASA programs and projects. The Center thus provides a central location to coordinate and conduct robust engineering and safety assessment across the entire Agency.

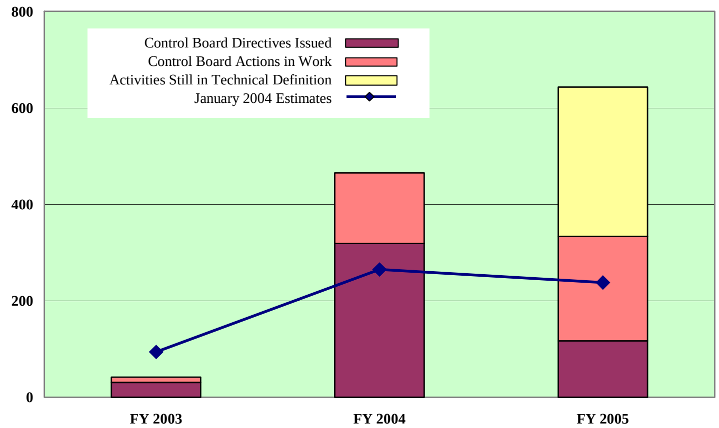
The following Chart 1 and associated Table 2 show the relative maturity of the estimates for known RTF content based on PRCB approval of technical content. Actions approved with PRCB directives issued have mature cost estimates, while those with control board actions in work are less mature. Both the content and cost estimates for RTF work that has not yet been reviewed by the control board are very preliminary and subject to considerable variation. The total cost for RTF will not be known until completion of the first Shuttle missions to the Space Station in FY 2005.

Cost estimates for FY 2005 and beyond will be refined as the Space Shuttle Program comes to closure on RTF technical solutions and the RTF plan is finalized. NASA expects that by late fall of 2004, a better understanding of the FY 2005 financial situation will be developed.

While all critical RTF work is continued, NASA will address any remaining FY 2005 shortfall first by seeking lower-priority offsets within the Shuttle Program, then by identifying funds for transfer from lower-priority or under-performing activities outside the Program.

The changes reflected on this page are corrections to typographical errors made during the publication process for Rev. 2.1. They do not reflect changes to the substance of the cost summary.

Chart 1. July 2004 Return to Flight Estimates



	FY 2003	FY 2004	FY 2005
Estimates Published in January 2004	***94***	***265***	***238***
Total Board Actions/Pending Board Action:	**42**	**465**	**643**
Value of Control Board Directives Issued	**31**	**319**	**117**
Estimates for Control Board Actions Work	**11**	**146**	**217**
Estimates for Activities Still in Technical Definition			**309**

Table 2. July 2004 Return to Flight Estimates

	FY 2003	FY 2004	FY 2005
TOTAL RTF	42	465	643
RTF Activities – Control Board Directive	31	319	117
RTF Activities – Been to Control Board/No Directive	11	146	217
RTF Activities – In Review Process	0	0	309
RTF Activities – Control Board Directive	31	319	117
Orbiter RCC Inspections & Orbiter RCC-2 Shipping Spares	2	38	0
On-orbit TPS Inspection & EVA Tile Repair	20	68	34
Orbiter TPS Hardening		28	1
Orbiter Certification/Verification		47	
Orbiter Other (GFE/Contingency)		15	16
External Tank Items (Camera, Bipod Ramp, etc.)		6	1
SRB Items (Bolt Catcher, ETA Ring Invest., Camera, other)	1	8	
Ground Camera Ascent Imagery Upgrade	8	40	3
Rudder Speed Brakes		5	11
Other (System Intgr. JB OSC Sys., Full Cost, Additional FTEs, etc.)		62	50
Stafford-Covey Team	0	3	1
RTF Activities – Been in Central Board/No Directive	11	146	217
Orbiter Workforce (Ground Ops)		5	5
External Tank Items (Camera, Bipod Ramp, etc.)	11	109	92
Ground Camera Ascent Imagery Upgrade			52
Orbiter Workforce (Ground Ops, USA, Boeing, Logistics Eng.)			32
KSC Ground Ops Workforce		32	36
RTF Activities – In Review Process	0	0	309
Orbiter RCC Inspections & Orbiter RCC-2 Shipsets Spares			
On-orbit TPS Inspection & EVA Tile Repair			
Orbiter TPS Hardening			
Orbiter Certification/Verification			
SRB Items (Bolt Catcher, Camera, other)			
Ground Camera Ascent Imagery Upgrade			
Increased SSME Testing			
SSME CAIB Impacts			
Other (System Intgr. JB OSC Sys., Full Cost, Additional FTEs, etc.)			

Columbia Accident Investigation Board

Recommendation 3.2-1

Initiate an aggressive program to eliminate all External Tank Thermal Protection System debris-shedding at the source with particular emphasis on the region where the bipod struts attach to the External Tank. [RTF]

BACKGROUND

Figure 3.2-1-1 illustrates the primary areas on the External Tank (ET) being evaluated as potential debris sources for return to flight (RTF).

ET Forward Bipod Background

Before STS-107, several cases of foam loss from the left bipod ramp were documented through photographic evidence. The most significant foam loss events in the early 1990s were attributed to debonds or voids in the "two-tone foam" bond layer configuration on the intertank area forward of the bipod ramp. The intertank foam was thought to have peeled off portions of the bipod ramp when liberated. Corrective action taken after STS-50 included implementation of a two-gun spray technique in the ET bipod ramp area (figure 3.2-1-2) to eliminate the two-tone foam configuration. After the STS-112 foam loss event, the ET Project began developing redesign concepts for the bipod ramp; this activity was still under way at the time of the STS-107 accident. Dissection of bipod ramps conducted for the STS-107 investigation has indicated that defects resulting from a manual foam spray operation over an extremely complex geometry could produce foam loss.

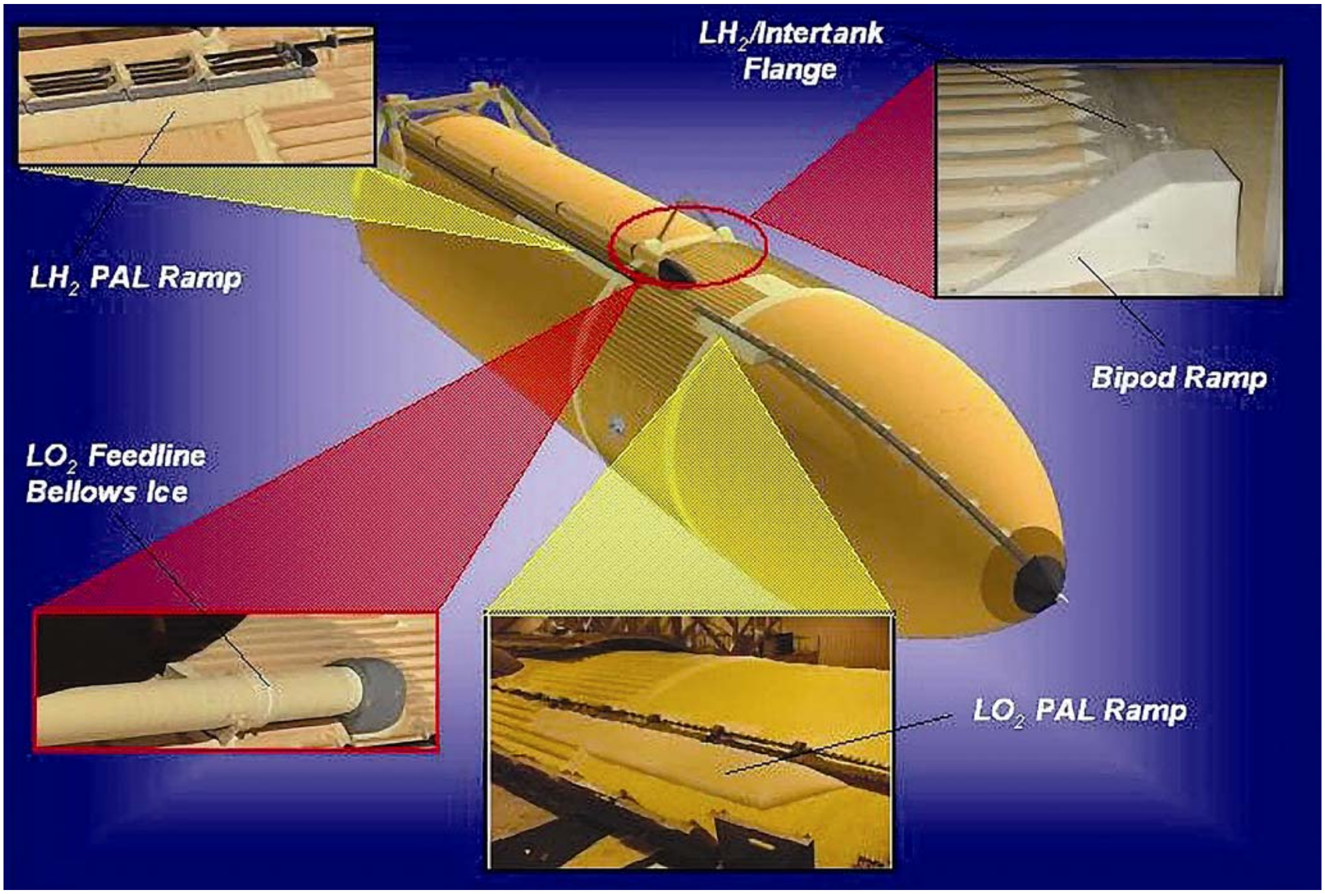


Figure 3.2-1-1. Primary potential ET debris sources being evaluated.

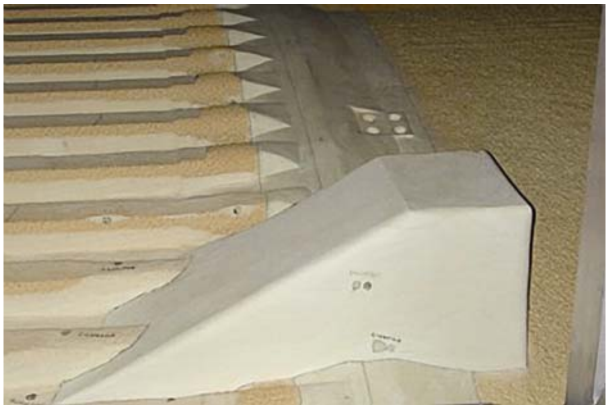


Figure 3.2-1-2. ET forward bipod ramp (foam).

Liquid Oxygen (LO_2) Feedline Bellows Background

Three ET LO_2 feedline sections incorporate bellows to allow feedline motion. The bellows shields (figure 3.2-1-3) are covered with Thermal Protection System (TPS) foam, but the ends are exposed. Ice and frost form when moisture in the air contacts the cold surface of the exposed bellows. Although Space Shuttle Program (SSP) requirements include provisions for ice on the feedline supports and adjacent lines, ice in this area presents a potential source of debris in the critical debris zone—the area from which liberated debris could impact the Orbiter.

Protuberance Airload (PAL) Ramps Background

The ET PAL ramps are designed to reduce adverse aerodynamic loading on the ET cable trays and pressurization lines (figure 3.2-1-4). PAL ramp foam loss has been observed on two prior flights, STS-4 and STS-7. The most likely cause of the losses was repairs and cryo-pumping (air-ingestion) into the Super-Light Ablator (SLA) panels under and adjacent to the PAL ramps. Configuration changes and repair criteria were revised early in the Program, thereby precluding the recurrence of these failures. However, the PAL ramps are covered with large, thick, manually sprayed foam applications

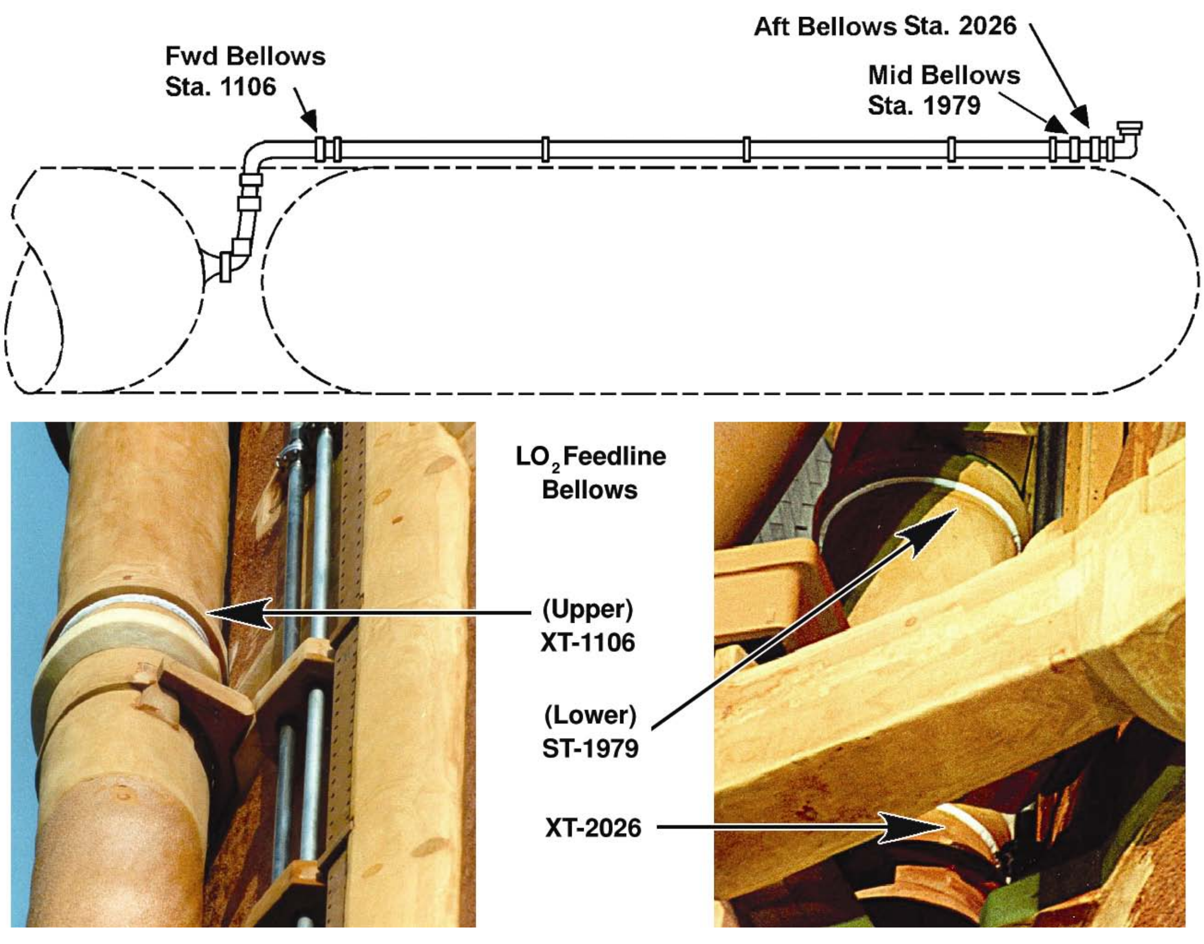


Figure 3.2-1-3. LO_2 feedline bellows.

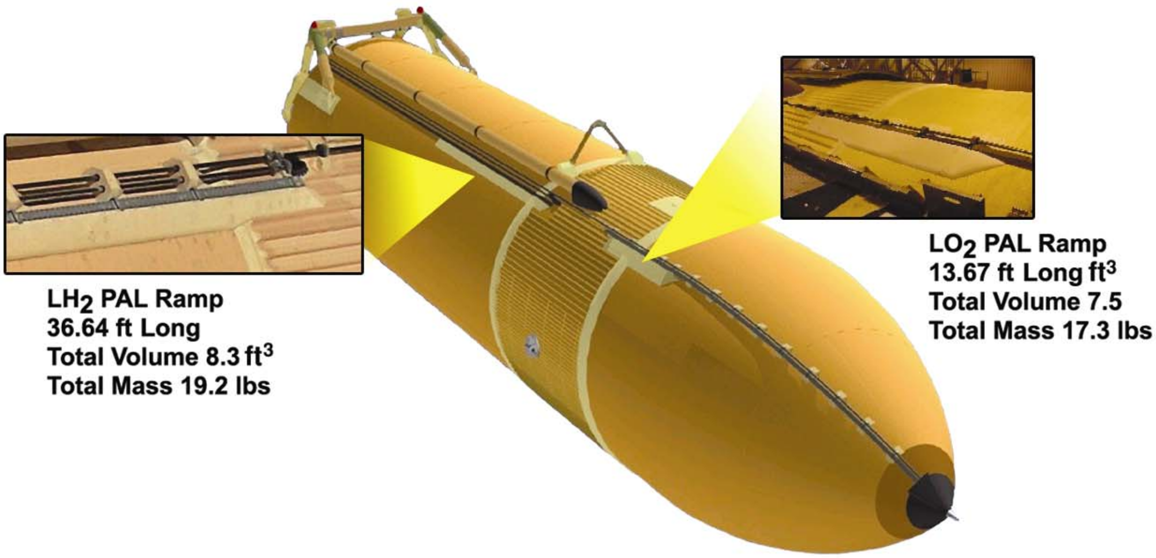


Figure 3.2-1-4. PAL ramp locations.

(using a less complex manual spray process than that used on the bipod) that could, if liberated, become the source of large debris.

ET Liquid Hydrogen (LH_2) Intertank Flange Background

The ET LH_2/intertank flange (figure 3.2-1-5) is a manually fastened mechanical joint that is closed out with a two-part manual spray foam application.

There is a history of foam loss from this area. The divots from the LH_2/intertank flange area typically weigh less than 0.1 lb. and emanate from within the critical debris zone, which is the area of the ET where debris loss could adversely impact the Orbiter or other Shuttle elements.

NASA IMPLEMENTATION

NASA has initiated a three-phase approach to eliminate the potential for debris loss from the ET. Phase 1 includes those activities that will be performed before return to flight. Phase 2 includes debris elimination enhancements that can be incorporated into the ET production line as the enhancements become available, but are not considered mandatory for RTF. Phase 3 represents potential long-term development activities that will be examined to achieve the ultimate goal of eliminating the possibility of debris loss. Implementation of Phase 3 efforts will be weighed against plans to retire the Shuttle after the completion of the International Space Station (ISS) assembly planned for the end of the decade.

As part of the Phase 1 effort, NASA is enhancing or redesigning the areas of known critical debris sources (figure 3.2-1-1). This includes redesigning the forward bipod fitting, eliminating ice from the LO_2 feedline bellows, and eliminating debris from the LH_2/intertank flange closeout. In addition to these known areas of debris, NASA is reassessing all TPS areas to validate the TPS configuration, including both automated and manual spray applications. Special consideration is being given to the LO_2 and LH_2 PAL ramps due to their size and location. This task includes assessing the existing verification data, establishing requirements for additional verification data, conducting tests to demonstrate performance against the devoting (cohesive-bond adhesion) failure mode, and evaluating methods to improve process control of the TPS application. NASA is also pursuing a comprehensive testing program to understand the root causes of foam shedding and develop alternative design solutions to reduce the debris loss potential. Research is being conducted at Marshall Space Flight Center, Arnold Engineering and Development Center, Eglin Air Force Base, and other sites. As part of this effort, NASA is developing nondestructive investigation (NDI) techniques to conduct ET TPS inspection without damaging the fragile insulating foam. During Phase 1, NDI will be used on the LO_2 and LH_2 PAL ramps as engineering information only; certification of the foam will be achieved primarily through validating the application processes.

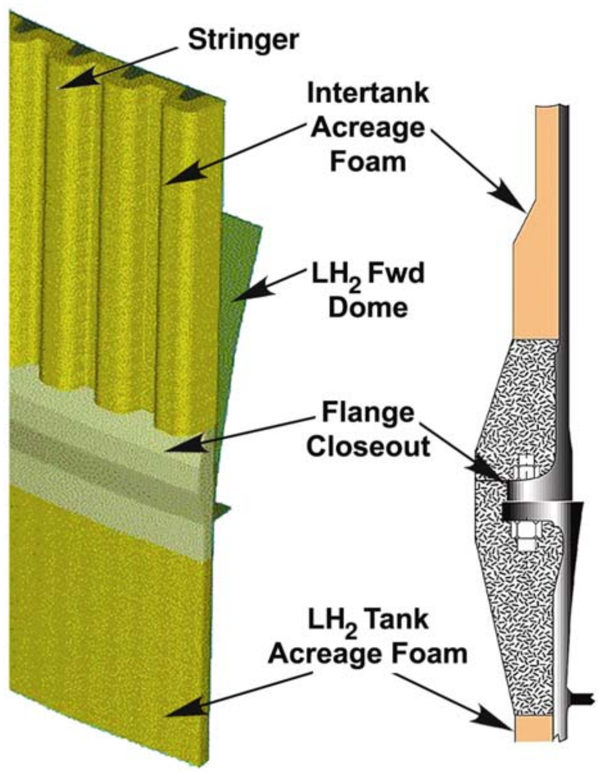


Figure 3.2-1-5. External Tank LH_2 flange area.

Phase 2 efforts include pursuing the automation of critical manual TPS spray processes, redesigning or eliminating the LO_2 and LH_2 PAL ramps, and enhancing the NDI screening tool. Efforts will also be made to enhance the TPS material to reduce its debris loss potential and to enhance the TPS thermal analysis tools to better size and potentially eliminate TPS on the vehicle.

The Phase 3 effort, if implemented, will examine redesigning the ET to eliminate the debris shedding potential at the source. This phase includes items such as developing a "smooth" LO_2 tank without external cable trays or pressurization lines, developing a smooth intertank in which an internal orthogrid eliminates the need for external stringers, and implementing a protuberance tunnel in the LH_2 tank. These changes could provide a tank with a smooth outer mold line (OML) that eliminates the need for complex TPS closeouts and manual sprays. NASA has approved further study for a concept and test plan that would rotate the LO_2 tank 180 degrees. If implemented, this concept would relocate all manually applied foam closeouts on the LO_2 tank outside of the critical debris zone.

ET Forward Bipod Implementation Approach

NASA has initiated a redesign of the ET forward bipod fitting (figure 3.2-1-6). The baseline design change eliminates the need for large bipod foam ramps. The bipod fittings have been redesigned to incorporate redundant heaters in the base of the bipod to prevent ice formation as a debris hazard.

LO_2 Feedline Bellows Implementation Approach

NASA evaluated three concepts to eliminate ice formation on the bellows (figure 3.2-1-7). Analysis and testing eliminated the flexible bellows boot as a potential solution since it could not eliminate ice formation within the available volume. The heated gaseous nitrogen (GN_2) or gaseous helium purge options were also eliminated since they did not reduce the potential for foam divot formation. NASA selected the condensate drain "drip lip" with a bellows cavity volume fill and retainer system for RTF retrofit. We will use a combination of analysis and testing to verify the effectiveness of the baselined design solution.

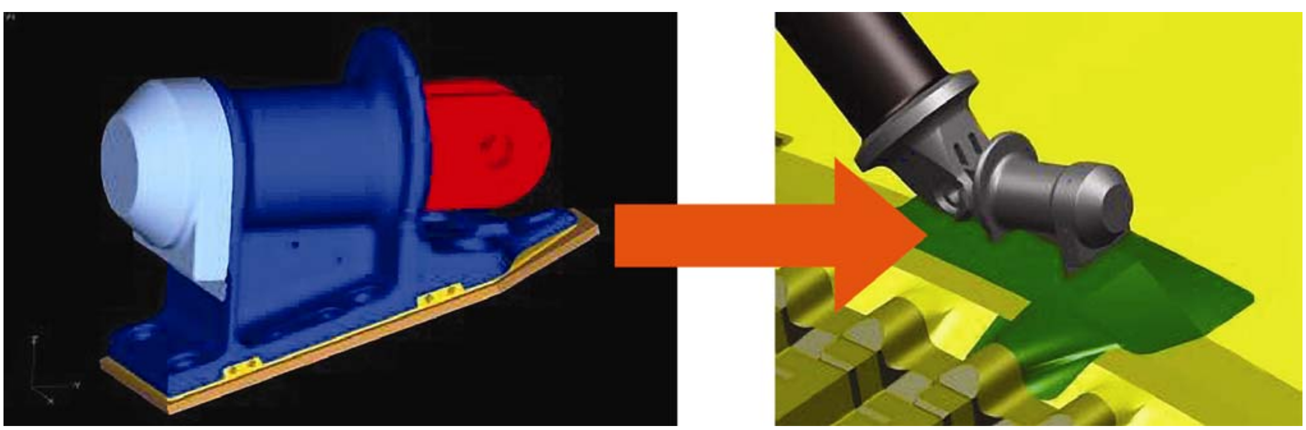


Figure 3.2-1-6. ET forward bipod redesign.

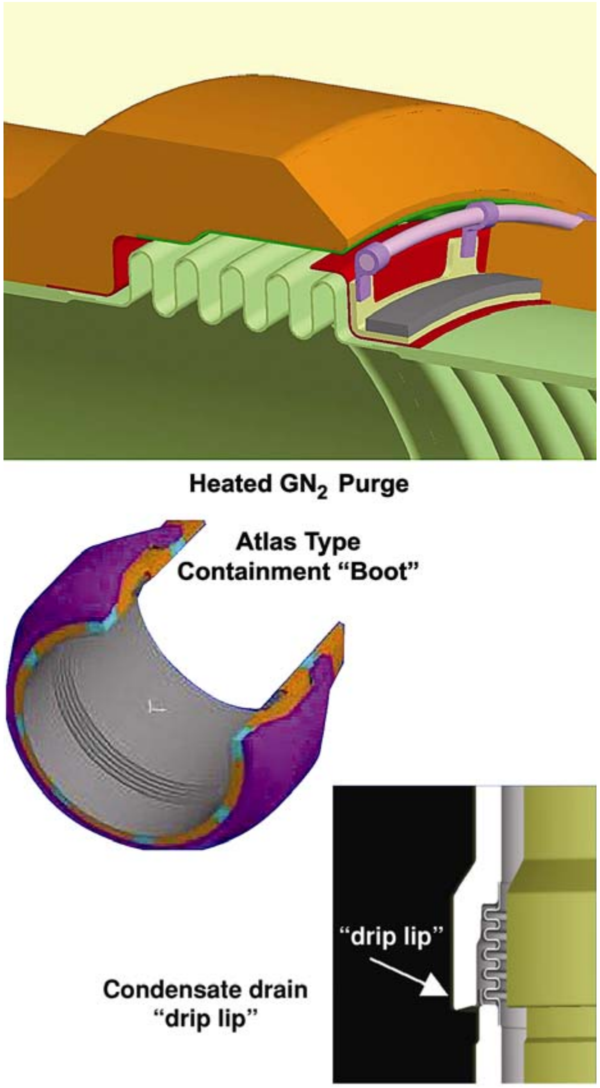


Figure 3.2-1-7. LO_2 feedline bellows design concepts.

LH_2/Intertank Flange Closeout Implementation Approach

NASA has conducted tests to determine the cause of foam liberation from the LH_2/intertank flange area. Migration of gaseous or liquid nitrogen from inside the intertank to voids in the foam was shown to be the root cause for LH_2/intertank flange foam losses during ground testing. Several design concepts have been evaluated to ensure that the LH_2/intertank flange closeouts will not generate critical debris in flight. These concepts ranged from active purge of the intertank crevice to enhanced foam application procedures. NASA also evaluated the concept of an inner mold line (IML) barrier to preclude the migration of liquid nitrogen present in the intertank crevice to the OML foam. The selected design solution incorporates an enhanced three-step manual closeout process to eliminate voids and preclude migration of liquid nitrogen from inside the intertank region to the foam.

An update to the original Level II debris transport analyses expanded the critical debris zone that must be addressed, and significantly reduced the allowable debris mass in this region. The critical debris zone was expanded from $\pm 67.5^o$ from the top of the External Tank (the top of the tank directly faces the underside of the Orbiter) to greater than $\pm 100^o$ from the top of the tank. As a result, a new closeout process for the thrust panel of the intertank flange region has been developed. The plan is to apply the new closeout to the entire thrust panel, expanding the enhanced closeout region to $\pm 112^o$ from the top of the tank (figure 3.2-1-8). NASA is continuing to refine these analyses.

PAL Ramps Implementation Approach

There have been two occurrences of PAL ramp foam loss events in the history of the Shuttle, on STS-4 and STS-7. These foam losses were related to cryo-pumping of air into SLA panels and repairs at this location. Subsequent changes in configuration and repair criteria reduced the potential for foam loss from this area. However, due to the size and location of the PAL ramps, NASA placed them at the top of the priority list for TPS verification reassessment and NDI.

NASA assessed the verification data for the existing PAL ramps and determined that the existing verification is valid. To increase our confidence in the verification data, NASA dissected similar hardware and conducted performance demonstration tests. Additional design capability and confidence tests will be performed to determine the additional margin for PAL ramp performance.

Plans for the redesign or removal of the PAL ramps are continuing as part of Phase 2 of the three-phase approach to eliminate the potential for debris loss from the ET. Three redesign solutions have been down-selected and will be subjected to wind tunnel testing: eliminating the ramps; reducing the size of the ramps; and redesigning the cable tray with a trailing edge fence. A wind tunnel test is planned for August 2004 to determine the potential for aerodynamic instabilities of the basic cable trays and associated hardware due to the proposed redesigns. The test articles will be instrumented with pressure transducers, strain gauges, and accelerometers to measure the aero elastic effect on the test articles.

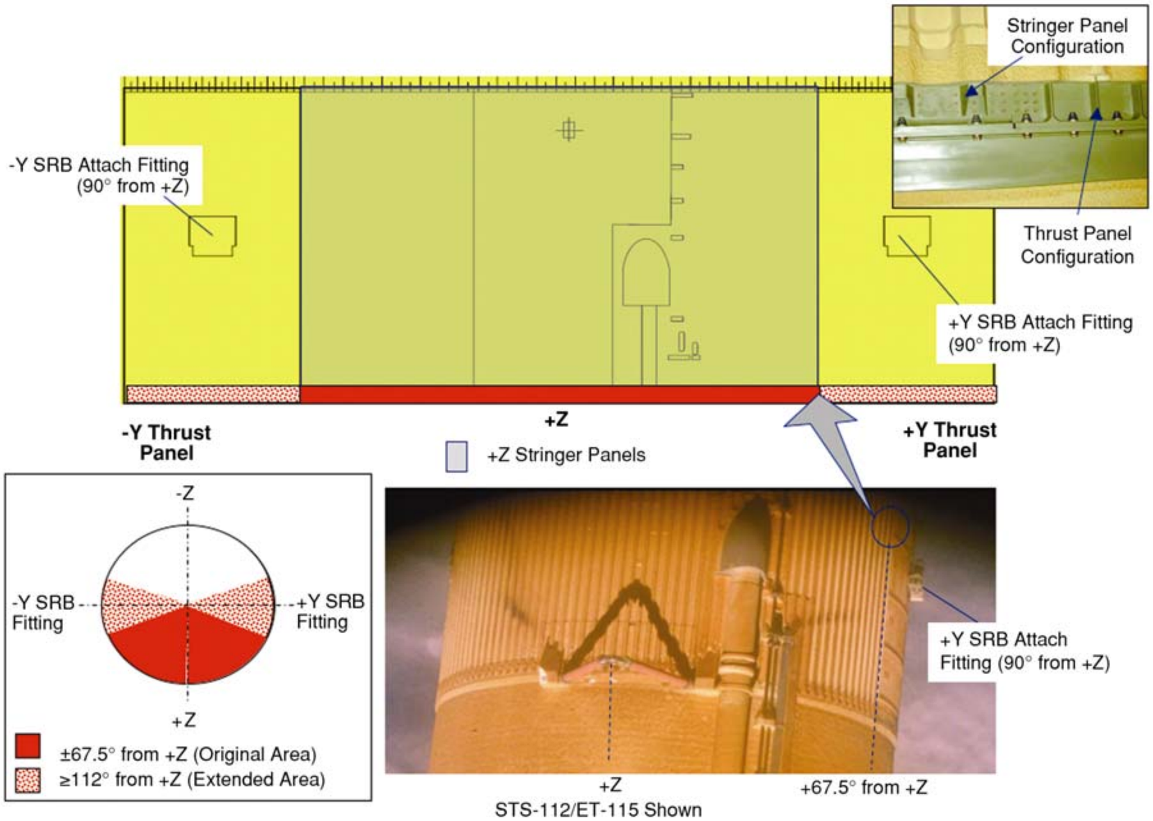


Figure 3.2-1-8. LH$_2$ intertank flange expanded debris zone.

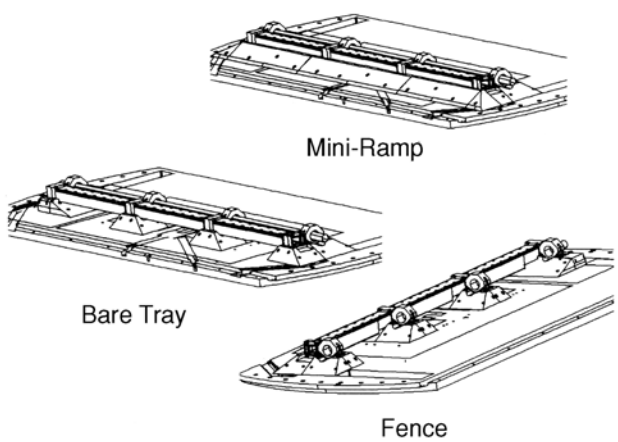


Figure 3.2-1-9. Leading edge fence LO$_2$ tray concept.

To protect against the possibility that ongoing tests prove that the existing PAL ramps are required, NASA is pursuing an automated spray system for the PAL ramps that could reduce the potential for foam shedding during launch (figure 3.2-1-9).

TPS (Foam) Verification Reassessment Implementation Approach

NASA has developed a certification plan for both manual and automated TPS applications in the critical debris zones. This assessment will be performed using the same approach applied to the PAL ramps: evaluating existing verification data, performing additional tests and analyses to demonstrate performance against critical failure modes, and reviewing and updating of the process controls applied to foam applications, especially the manual spray applications that have a greater risk of foam loss. For future TPS applications, NASA will ensure that at least two certified production operations personnel attend all final closeouts and critical hand-spraying procedures to ensure proper processing and that updates to the process controls are applied to the foam applications (ref. Recommendation 4.2-3).

NDI of Foam Implementation Approach

NASA is pursuing development of TPS NDI techniques to improve confidence in the foam application processes. If successful, advanced NDI will provide an additional level of process verification. The initial focus for RTF was on applying NDI to the PAL ramps. However for RTF, NASA will rely on the existing foam application process verification rather than on NDI to clear the tanks for flight.

During Phase 1, NASA surveyed state-of-the-art technologies, evaluated their capabilities, down-selected, and began developing a system to detect critical flaws in ET insulation systems. At an initial screening, test articles with known defects, such as voids and delaminations (figure 3.2-1-10), were provided to determine detection limits of the various NDI methods.

After the initial screening, NASA selected the Terahertz and backscatter radiation technologies and conducted more comprehensive probability of detection (POD) tests for those applicable NDI methods. The Phase 2 activities will optimize and fully certify the selected technologies for use on the ET.

STATUS

NASA has completed an initial assessment of debris sources on the ET, including both credible debris size and frequency or probability of liberated debris.

ET Forward Bipod Status

NASA has successfully completed a Systems Design Review (SDR) and a Preliminary Design Review (PDR). The Critical Design Review (CDR) was held in November 2003, with a Delta CDR in June 2004. The Delta CDR Board approved the Bipod redesign. A Production Readiness Review (PRR) was held in June 2004. The PRR board gave approval for Manufacturing Operations to proceed with the Bipod wedge foam spray on ET-120, which is now complete. The wedge spray is a foam closeout that serves as a transition area for routing of the heater harnesses from the fitting base into the intertank. The wedge is applied prior to fitting installation; and after the fitting installation is complete, the final Bipod closeout is performed.. Thermal verification tests on prelaunch ice prevention have been conducted, with an automated heater control baselined and validated based on bipod web temperature measurements. Structural verification tests have confirmed the performance of the modified fitting in flight environments. Wind tunnel testing has verified the TPS closeout performance when exposed to ascent aerodynamic and thermal environments. Remaining open work includes finalizing the TPS process control and verification approach for the foam application, and conducting an integrated bipod test using hydrogen, the tank fluid, and a prototype ground control system.

LO_2 Feedline Bellows Status

NASA selected the TPS “drip lip” option to address ice formation on the LO_2 feedline bellows. The drip lip diverts condensate from the bellows and significantly reduces ice formation. NASA selected a cavity volume fill and retainer system (figure 3.2-1-11) as the design solution for the three-part bellows closeout. This system offered reduced implementation complexity and the ability to support both forward and aft bellows. The drip lip design is nearly complete. Additional testing is required to qualify the volume fill material and verify the retainer system performance.

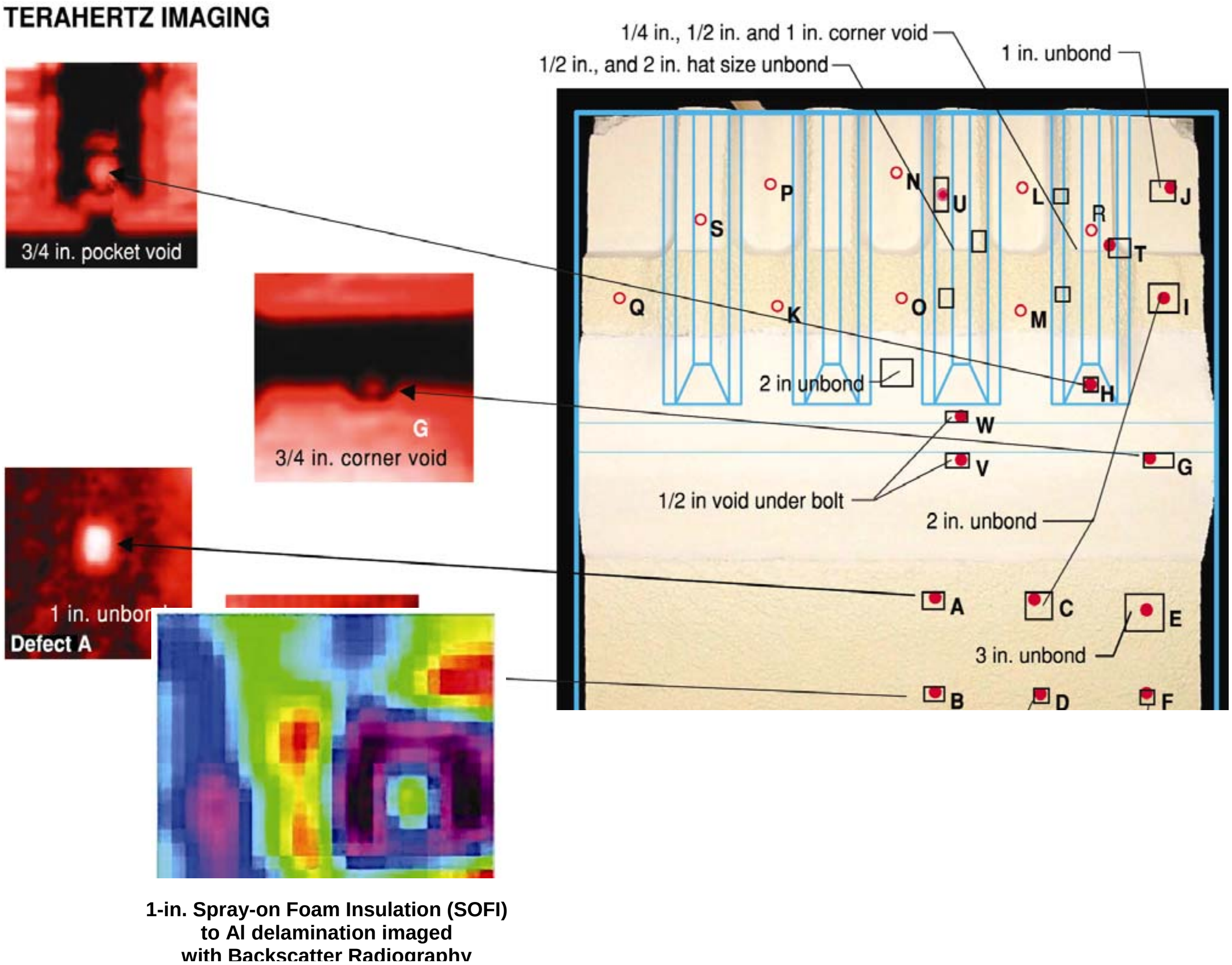


Figure 3.2-1-10. Terahertz images.

Condensate drain "drip lip"

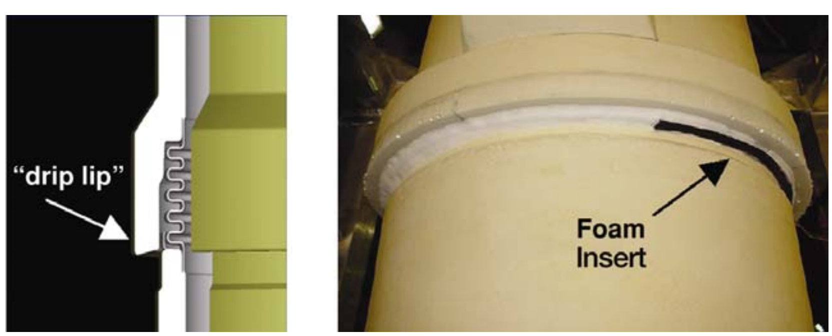


Figure 3.2-1-11. LO_2 feedline bellows "drip lip" with foam insert.

LH_2/Intertank Flange Closeout Status

NASA has successfully determined the root cause of foam loss. Liquid nitrogen was formed when the gaseous nitrogen used as a safety purge in the intertank came into contact with the extremely cold hydrogen tank dome and condensed into liquid. The liquid nitrogen migrated through intertank joints, fasteners, vent paths, and other penetrations into the foam and then filled voids in the foam caused by unacceptable variability in the manual foam application. During ascent, the liquid nitrogen returned to a gaseous state, pressurizing the voids and causing the foam to detach.

NASA evaluated the foam loss in this region through rigorous testing and analysis. First, a series of 1′×1′ aluminum substrate panels with induced voids of varying diameters and depths below the foam surface were subjected to the vacuum, heat profiles, and backface cryogenic temperatures experienced during launch. These tests were successful at producing divots in a predictable manner.

Follow-on testing was conducted on panels that simulated the liquid hydrogen intertank flange geometry and TPS closeout configuration to replicate divot formation in a flight-like configuration. Two panel configurations were simulated, a 3-stringer configuration and a 5-stringer configuration. The panels were subjected to flight-like conditions, including front face heating, backface cryogenics (consisting of a 1.5-hour chill-down, 5-hour hold, and 8-minute heating), ascent pressure profile, and flange deflection. These tests were successful at demonstrating the root cause failure mode for foam loss from the LH_2 tank/intertank flange region.

With this knowledge, NASA evaluated the LH_2/intertank closeout design to minimize foam voids and nitrogen leakage from the intertank into the foam (figure 3.2-1-5). Several design concepts were initially considered to eliminate debris, including incorporating an active helium purge of the intertank crevice to eliminate the formation of liquid nitrogen and developing enhanced foam application procedures.

Testing indicated that a helium purge would not completely eliminate the formation of foam divots, since helium, too, could produce enough pressure in the foam voids to cause divot formation. As a result, the purge solution was eliminated from consideration.

NASA also pursued a concept of applying a volume fill or barrier material in the intertank crevice to reduce or eliminate nitrogen condensation migration into the voids. However, analyses and development tests showed that the internal flange seal and volume fill solution may not be totally effective on tanks that had existing foam applications. As a result, this concept was also eliminated from consideration.

An alternate mitigation is to remove the gaseous oxygen and gaseous hydrogen press lines to allow access to additional flange bolts for reversal and application of sealant. The existing intertank closeout would be removed and replaced with the three-step enhanced closeout. NASA is focusing on the enhanced TPS closeout in the LH_2 intertank area to reduce the presence of defects within the foam by using a three-step closeout procedure. This approach greatly reduces or eliminates void formations in the area of the flange joining the liquid hydrogen tank to the intertank.

In addition, a study has been performed at both KSC and the Michoud Assembly Facility (MAF) to reduce the potential for TPS damage during ground processing. The study identified a series of recommendations, including reducing access to critical areas of the ET, installing debris safety barriers, improving the work platforms in the area, and investigating a topcoat that would more readily show handling damage. Testing performed on eight panels using the enhanced closeout configuration demonstrated the effectiveness of the closeout; there were no foam cracks or divots formed in any of the tests.

NASA now understands the failure mechanism of the foam and will implement redundant solutions. The baseline flange closeout enhancement (±112° from the +Z, excluding area under LO_2 feedline and cable tray) uses a multi-pronged approach. The baseline includes the external three-step closeout, point fill of the structure, reversal of the flange bolts, and sealant on the threads of the bolts. The external three-step enhanced procedure reduces foam loss to a level within acceptable limits by removing critical voids in the foam.

PAL Ramp Status

Because the PAL ramps (figure 3.2-1-12) have an excellent flight history, NASA's baseline approach for RTF is to develop sufficient certification data to accept the minimal debris risk of the existing design. Evaluating the available verification data and augmenting it with additional tests, analyses, and/or inspections will accomplish this. This will include dissecting several existing PAL ramps to understand the void sizes produced by the existing PAL ramp TPS process.

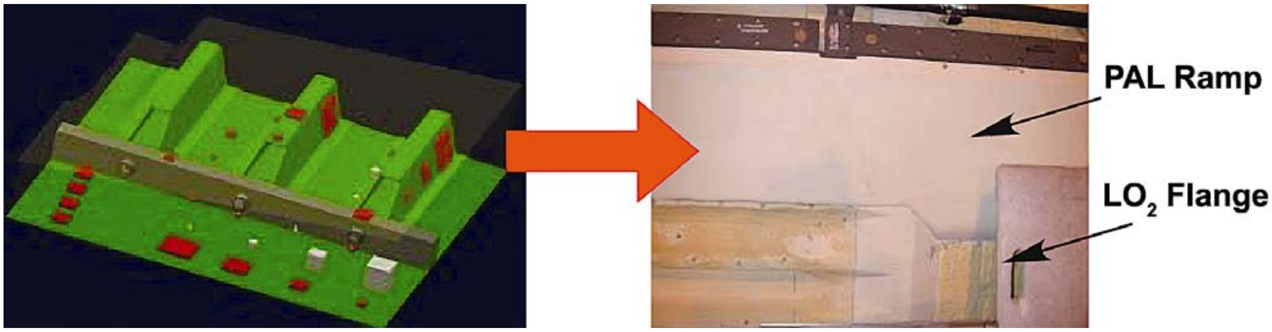


Figure 3.2-1-12. PAL ramp/flange test panel.

NASA has obtained sufficient data to proceed to launch with the existing LO_2 and LH_2 PAL ramps. The LH_2 PAL ramp is approximately 38 feet in length. A portion of the LH_2 PAL ramp spans the high-risk LH_2 flange closeout. The forward 10 feet of the LH_2 PAL ramp have been removed to access the underlying intertank/LH_2 tank flange closeout. By removing the10-foot section, an enhanced LH_2/intertank flange closeout can be performed. The removed portion of the LH_2 PAL ramp will be replaced with an improved process manual spray application. In addition, an automated PAL ramp spray is being evaluated for Phase 2 activities following RTF.

Concept design activities are also in work to eliminate the PAL ramps as part of the Phase 2 activity. Redesign options include eliminating the PAL ramps altogether, implementing smaller mini-ramps, or incorporating a cable tray aero block fence on either the leading or trailing edge of the tray. NASA conducted subscale wind tunnel testing of the candidates that indicated a good potential for eliminating the foam PAL ramps. Additional wind tunnel tests are planned for this spring and summer.

TPS (Foam) Verification Reassessment Status

The SSP has established a TPS Certification Plan for the ET RTF efforts. This plan will be applied to each TPS application within the critical debris zone. Evaluating the available verification data and augmenting them with additional tests, analyses, and/or inspections will accomplish this plan. It also includes dissection of all TPS applications within the critical debris zone to understand the void sizes produced by the existing TPS processes.

All TPS applications will undergo visual inspection, verification of the sprays to specific acceptance criteria, and validation of the acceptance criteria. A series of materials properties tests is being performed to provide data for analysis reflecting a statistical lower bound for hardware performance. Acceptance testing, including raw and cured materials at both the supplier and the MAF, is being used to demonstrate the as-built hardware integrity is consistent with design requirements and test databases. Mechanical property tests, including plug pull, coring, and density, are being performed on the as-built hardware.

NASA is also conducting stress analysis of foam performance under flight-like structural loads and environmental conditions, with component strength and fracture tests grounding the assessments. Production-like demonstrations are being performed upon completion of all design and development efforts to verify and validate the acceptability of the production parameters. Dissection of equivalent or flight hardware is under way to determine process performance. TPS defect testing is being conducted to determine the critical defect sizes for each application. In addition, a variety of bond adhesion, cryoflex, storage life verification, cryo/load/thermal tests, and acceptance tests are under way to fully certify the TPS application against all failure modes. Finally, a Manual Spray Enhancement Team has been established to provide recommendations for improving the TPS closeout of manual spray applications.

NDI of Foam Status

Activities have been initiated to develop NDI techniques for use on ET TPS. The following prototype systems under development by industry and academia were evaluated:

- Backscatter Radiography: University of Florida
- Microwave/Radar: Marshall Space Flight Center, Pacific Northwest National Labs, University of Missouri, Ohio State
- Shearography: Kennedy Space Center, Laser Technology, Inc.

- Terahertz Imaging: Langley Research Center, Picometrix, Inc., Rensselaer
- Laser Doppler Vibrometry: Marshall Space Flight Center, Honeywell

The Terahertz Imaging and Backscatter Radiography systems were selected for further probability of detection (POD) testing based on the results of the initial proof-of-concept tests. The microwave system will still be evaluated during the Phase 2 development activity. This additional POD testing has been completed, but the results are still being analyzed. The preliminary results, however, indicate that these technologies are not yet reliable enough to be used to certify TPS applications over complex geometries, such as the bipod or intertank flange regions. The technologies will continue to be developed to support PAL ramp evaluation and for Phase 2 implementation.

FORWARD WORK

- Finalize critical characteristics that could cause catastrophic damage to the Orbiter.
- Complete the redesigned hardware verification testing.
- Complete the TPS certification activities, including generating the materials properties, obtaining the dissection results, determining the critical debris size for each application, and completing the required assessments.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Apr 04 (Completed)	Perform NDI of PAL ramp on ET-102 (1^{st} RTF rank)
SSP	Jun 04 (Completed)	Complete bipod redesign Delta CDR Board
SSP	Jul 04 (Completed)	Complete validation of LH_2/intertank stringer panel closeout
SSP	Aug 04	Complete validation of LH_2/intertank thrust panel closeout
SSP	Aug 04	Complete bipod TPS closeout validation
SSP	Aug 04	Complete bellows “drip lip” validation
SSP	Aug 04	Complete bipod retrofit of ET-120
SSP	Sep 04	Complete flange closeout on ET-120
SSP	Oct 04	Ready to ship ET-120 to KSC

Columbia Accident Investigation Board

Recommendation 3.3-2

Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes. [RTF]

BACKGROUND

The STS-107 accident demonstrated that the Space Shuttle Thermal Protection System (TPS) design is vulnerable to impact. Identification of all sources of debris and potential modifications to the design of the TPS, referred to as Orbiter hardening, are expected to make the Orbiter less vulnerable to this risk.

NASA IMPLEMENTATION

A Program Requirements Control Board (PRCB) action authorized assessment of potential TPS modifications for Orbiter hardening. As part of this action, NASA is defining candidate redesigns that will reduce impact damage risk to vulnerable TPS areas and is developing an assessment plan for other steps to improve Orbiter hardening.

Initially, a Space Shuttle Program (SSP)-chartered planning team identified 17 specific design options that fell into eight broad design families. Further testing and analysis, combined with new data from the ongoing *Columbia* Accident Investigation Board investigation, led NASA to hone its criteria for defining and prioritizing Orbiter hardening options. Each TPS enhancement option was evaluated against the damage history, vulnerability, and criticality potential of the area and the potential safety, operations, and performance benefits of the enhancement. The team focused on those changes that achieve the following goals: increased impact durability for ascent and micrometeoroid and orbital debris impacts; increased temperature capability limits; reduced leak paths; added entry redundancy; increased contingency trajectory limits; and reduced contingency operations. These candidates were presented to the SSP PRCB, which prioritized them, eliminating seven from further consideration. Some of the remaining ten options required breaking down into smaller elements. The result was a final set of 15 Orbiter hardening options grouped into eight different design families. These results were presented to the PRCB in June 2003, including forward action plan recommendations for the revised design families (see table 3.3-2-1).

The SSP has established a plan to determine the impact resistance of both Reinforced Carbon-Carbon (RCC) and tiles in their current configurations. The SSP is also working to identify all debris sources from all Space Shuttle elements including the External Tank (ET), the Solid Rocket Boosters, and the Orbiter. Additional detail on this work can be found in SSP-14, Critical Debris Size. The SSP Systems Engineering and Integration Office is providing transport analyses to identify potential velocity, impact location, and impact angle for the debris sources. In parallel, an impact test program is being conducted to determine the impact resistance of RCC and tile using various debris sources under conditions that encompass the full range of parameters provided by the transport analysis. The data generated from this testing will be used to correlate an accurate set of analytical models to further understand the damage threat. Further testing will be conducted on specific Orbiter insulation configurations that were identified during the investigation, including the leading edge structural subsystem access panels (located directly behind the RCC) and the edge tile configuration of the main landing gear doors (MLGD).

STATUS

NASA has fully complied with the *Columbia* Accident Investigation Board (CAIB) Recommendation 3.3-2 and initiated an Orbiter hardening program to increase the Orbiter's capability to sustain minor debris damage. Orbiter hardening options that are constraints to return to flight (RTF) have either been implemented or are being implemented at this time. Other feasible hardening options that are approved by the SSP will be implemented on the vehicle when opportunities become available.

For each of the redesign options, NASA is developing a detailed feasibility assessment that will include cost and schedule for either full implementation or for the next proposed phase of the project. The Orbiter hardening options have been grouped into three categories based on the implementation phasing. The three phases are defined as follows:

Family	Redesign Proposal	Phase
WLESS	"Sneak Flow" Front Spar Protection (RCC #5 – 13)	I
	"Sneak Flow" Front Spar Protection (RCC # 1 – 4, 4 – 22)	II
	Lower Access Panel Redesign/BRI 20 Tile Implementation	III
	Insulator Redesign	III
	Robust RCC	III
Landing Gear and ET Door Thermal Barriers	Main Landing Gear Door Corner Void	I
	Main Landing Gear Door Enhanced Thermal Barrier Redesign	II
	Nose Landing Gear Door Thermal Barrier Material Change	III
	External Tank Door Thermal Barrier Redesign	III
Vehicle Carrier Panels – Bonded Stud Elimination	Forward RCS Carrier Panel Redesign – Bonded Stud Elimination	I
Tougher Lower Surface Tiles	Tougher Periphery (BRI 20) Tiles around MLGD, NLGD, ETD, Window Frames, Elevon Leading Edge and Wing Trailing Edge	III
	Tougher Acreage (BRI 8) Tiles and Ballistics SIP on Lower Surface	III
Instrumentation	TPS Instrumentation	III
Elevon Cove	Elevon Leading Edge Carrier Panel Redesign	III
Tougher Upper Surface Tiles	Tougher Upper Surface Tiles	III
Vertical Tail	Vertical Tail AFSI High Emittance Coating	III

Table 3.3-2-1. Eight Design Families Targeted for Enhancement.

Phase I options will be implemented before RTF. Phase II options will be implemented as soon as engineering designs are complete and modification opportunities are identified. Phase III consists of potential long-term options that will increase the Orbiter's impact resistance capability. These will be implemented as material development is completed and opportunities become available.

Phase I work includes elimination of MLGD corner void, elimination of Forward Reaction Control System (FRCS) bonded studs, and wing spar protection for the most vulnerable RCC panels 5 through 13. The interim MLGD corner void elimination modification is complete on Orbiter Vehicle (OV)-103 and OV-104; this modification will improve thermal protection in the forward and aft outboard corners of the MLGD cavity. OV-105 will receive the same interim modification unless NASA is able to proceed to the planned final modification with redundant thermal barriers. FRCS-bonded studs will be replaced with mechanically fastened studs on all three vehicles. This will ensure stronger attachment points for key carrier panels. This replacement is complete on OV-103. OV-104 and OV-105 are scheduled to receive the same modification in the next few months. The design for wing spar protection modification behind RCC panels 5 through 13 is complete. This modification will increase the Orbiter's ability to successfully enter the Earth's atmosphere with minor wing leading edge (WLE) damage. OV-103 and OV-104 will initially receive this modification. On OV-105, all 22 RCC panel locations on both wings will receive wing spar protection during the current Orbiter Major Modification.

Phase II work includes MLGD-enhanced thermal barrier redesign and wing spar protection for all remaining RCC panels. The designs to modify the wing spar protection behind RCC panels 1 through 4 and 14 through 22 on OV-103 and OV-104 will be finalized at the end of August 2004.

All Phase III options are under review by the SSP at this time with two exceptions that have been approved and are in development: toughened lower and upper surface tiles and Robust RCC. Work is continuing on the analysis and preliminary design phase for these two items and will be completed by January 2005. A feasibility study of the Robust RCC option will conclude in the October 2004 timeframe. SSP has approved the proposal to continue into the formulation phase of the Robust RCC option, which will conclude in early 2005.

NASA's Orbiter Debris Impact Assessment Team is making significant progress in determining the actual damage resistance of current materials. Testing is nearly complete to establish the material properties of tile, RCC, and potential debris that may impact the TPS. These data will help NASA build models that determine damage thresholds. Impact testing of foam against tile is more than 75% complete. Ice impact testing against tile is 25% complete. The first series of ice impacts against RCC is scheduled to begin in early August. Work on the analytical models is progressing on schedule.

Damage assessment tests are ongoing at the Langley Research Center (LaRC) in Virginia. These tests are designed to show the structural strength of RCC after impact. Combined with thermal data from ablative testing of damaged RCC coupons at the Johnson Space Center Arc Jet Facility, the LaRC data will allow development of a set of analytical models that will determine the amount of RCC damage that must be repaired to return safely to Earth. Thermal models and testing to predict damaged tile capabilities are also in work.

Initial tests of ablator material against tile showed unacceptable levels of damage; however, there is no operational history of ablator impacts, and the SSP believes that the Shuttles can be certified for no release of ablators during ascent. Consistent with these findings, SSP is formulating a new requirement that will allow no release of ablator or metal debris.

Based on recent impact testing of aluminum oxide particles and ET foam against the Orbiter windows, the SSP approved the early implementation of a modification to increase the thickness of the Orbiter's two side windows (windows 1 and 6). This modification will provide increased protection against potential aluminum oxide particle strikes (aluminum oxide is a byproduct of the Solid Rocket Booster separation motor firing) and provides protection against potential ET foam strikes. This modification had been previously approved by the SSP for enhanced debris protection, but was only to be implemented on an attrition basis; it will now be implemented prior to RTF. Testing of ice against windows is expected to begin in September 2004 at the Glenn Research Center.

FORWARD WORK

NASA will continue to implement the plan according to the schedule below. Decision packages for each redesign option will be brought to the PRCB for disposition. NASA will review our response to this CAIB recommendation with the Stafford Covey Return to Flight Task Group.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jun 03 (Completed)	Initial plan reported to PRCB
SSP	Aug 03 (Completed)	Initial Test Readiness Review held for Impact Tests
SSP	Nov 03 (Completed)	Phase I Implementation Plans to PRCB (MLGD corner void, FRCS carrier panel redesign—bonded stud elimination, and WLE impact detection instrumentation)
SSP	Jan 04 (Completed)	Phase II Implementation Plans to PRCB (WLE front spar protection and horse collar redesign, MLGD redundant thermal barrier redesign)
SSP	Aug 04	Finalize designs for modified wing spar protection between RCC panels 1–4 and 14–22 on OV-103 and OV-104
SSP	Oct 04	Conclude feasibility study of the Robust RCC option
SSP	Jan 05	Complete analysis and preliminary design phase for upper and lower surface tiles and robust RCC
SSP	TBD	Phase III Implementation Plans to PRCB (include robust RCC, ET door thermal barrier redesign, elevon cove leading edge carrier panel redesign, etc.)

Columbia Accident Investigation Board

Recommendation 6.4-1

For missions to the International Space Station, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System, including both tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities available when near to or docked at the International Space Station.

For non-Station missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.

Accomplish an on-orbit Thermal Protection System inspection, using appropriate assets and capabilities, early in all missions.

The ultimate objective should be a fully autonomous capability for all missions to address the possibility that an International Space Station mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after undocking. [RTF]

BACKGROUND

The Board determined, and NASA accepts, that an on-orbit Thermal Protection System (TPS) inspection and repair capability is an important part of the overall TPS risk mitigation plan. Currently, Shuttle flights are planned only to the International Space Station (ISS), and, as outlined in the Vision for Space Exploration, NASA will retire the Space Shuttle fleet following assembly of the ISS.

There are additional risks associated with creating and deploying a fully autonomous inspection capability without ISS resources. Therefore, NASA has decided to focus its development of TPS inspection and repair on those capabilities that enhance the Shuttle's suite of assessment and repair tools while taking full advantage of ISS resources.

The Space Flight Leadership Council has directed the Space Shuttle Program (SSP) to focus its efforts on developing and implementing inspection and repair capability appropriate for the first return to flight missions using ISS resources as required. NASA will focus its efforts on mitigating the risk of multiple failures (such as an ISS mission failing to achieve the correct orbit or dock successfully, or the Orbiter being damaged during or after undocking and suffering critical TPS damage) through maximizing the Shuttle's ascent performance margins to achieve ISS orbit, using the docked configuration to maximize inspection and repair capabilities, and flying protective attitudes following undocking from the ISS. However, NASA will continue to analyze the relative merit of different approaches to mitigating the risks identified by the *Columbia* Accident Investigation Board.

This approach to avoiding unnecessary risk has also led NASA to recognize that autonomous missions carry a higher risk than ISS missions. A brief summary of the additional risks associated with autonomous missions is described below:

1. *Lack of Significant Safe Haven*. The inability to provide a "safe haven" while inspection, repair, and potential rescue are undertaken creates additional risk in autonomous missions. On missions to the ISS it may be possible to extend time on orbit to mount a well-planned and -equipped rescue mission. NASA is continuing to study this contingency scenario. For autonomous missions, however, the crew would be limited to an additional on-orbit stay of no more than two to four weeks, depending on how remaining consumables are rationed. The Safe Haven concept is discussed in detail in SSP-3.

2. *Unprecedented Double Workload for Ground Launch and Processing Teams*. Because the rescue window for an autonomous mission is only two to four weeks, NASA would be forced to process two vehicles for launch simultaneously to ensure timely rescue capability. Any processing delays to one vehicle would require a delay in the second vehicle. The launch countdown for the second launch would begin before the actual launch of the first vehicle.

This short time period for assessment is a serious concern. It would require two highly complex processes to be carried out simultaneously, and it would not permit thorough assessment by the launch team, the flight control team, and the flight crew.

3. *No Changes to Cargo or Vehicle Feasible*. Because of the very short timeframe between the launch of the first vehicle and the requirement for a rescue flight, no significant changes could reasonably be made to the second vehicle. This means that it would not be feasible to change the cargo on the second Space Shuttle to support a repair to the first Shuttle, add additional rescue hardware, or make vehicle modifications to avoid whatever situation caused the need for a rescue attempt in the first place. Not having sufficient time to make the appropriate changes to the rescue vehicle or the cargo could add significant risk to the rescue flight crew or to crew transfer. The whole process would be under acute schedule pressure and undoubtedly many safety and operations waivers would be required.

4. *Rescue Mission*. Space Shuttles routinely dock with the ISS, and Soyuz evacuation procedures are supported by extensive training, analysis, and documentation. A rescue from the ISS, with multiple hatches, airlocks, and at least one other vehicle available (Soyuz), is much less complex and risky than that required by a stranded Space Shuttle being rescued by a second Space Shuttle. When NASA first evaluated free-space transfer of crew, which would be required to evacuate the Shuttle in an autonomous mission, many safety concerns were identified. This analysis would need to be done again, in greater detail, to identify all of the potential issues and safe solutions.

5. *TPS Repair*. NASA's current planned TPS repair method for an ISS-based repair uses the ISS robotic arm to stabilize an extravehicular activity (EVA) crew person over the worksite. This asset is not available for an autonomous mission, so NASA would have to finish development of an alternate method for stabilizing the crewmember. Such a concept is in development targeting 2006, when it will be needed for ISS-based repairs also. Solving this problem before 2006 represents a challenging undertaking.

NASA IMPLEMENTATION

Note: the remainder of this section refers to inspection and repair during nominal Shuttle missions to the ISS.

Taken together, TPS inspection and repair represent one of the most challenging and extensive return to flight tasks. NASA's near-term TPS risk mitigation plan calls for:

- Space Shuttle vehicle modifications to eliminate the liberation of critical debris
- Fielding improved ground and vehicle-based cameras
- Developing ship-based radar and airborne sensors for ascent debris tracking
- Adding wing leading edge (WLE) impact sensors for debris detection and damage assessment
- On-orbit TPS surveys using the Shuttle Remote Manipulator System (SRMS) and Space Station Remote Manipulator System (SSRMS) cameras
- ISS crew observations during Shuttle approach and docking

Techniques for repairing tile and Reinforced Carbon-Carbon (RCC) by EVA are under development. The combination of these capabilities will help to ensure a low probability that critical damage will be sustained, while increasing the probability any damage that does occur can be detected and the consequences mitigated in flight.

NASA's long-term TPS risk mitigation steps will refine and improve all elements of the near-term plan, ensuring an effective inspection and repair capability.

Inspection

The first step in structuring effective inspections is to establish baseline criteria for resolving critical damage. NASA has defined preliminary critical damage inspection criteria that form the basis for TPS inspection and repair development work. The detailed criteria are evolving based on ongoing tests and analyses. Our goal is to define damage thresholds for all TPS zones, below which no repair is required before entry. These criteria are a function of the damage surface dimensions, depth, and entry heating at each location on the vehicle. The preliminary criteria are shown in figure 6.4-1-1.

A combination of Shuttle and ISS assets will be capable of imaging critical TPS damage in all areas. The Orbiter

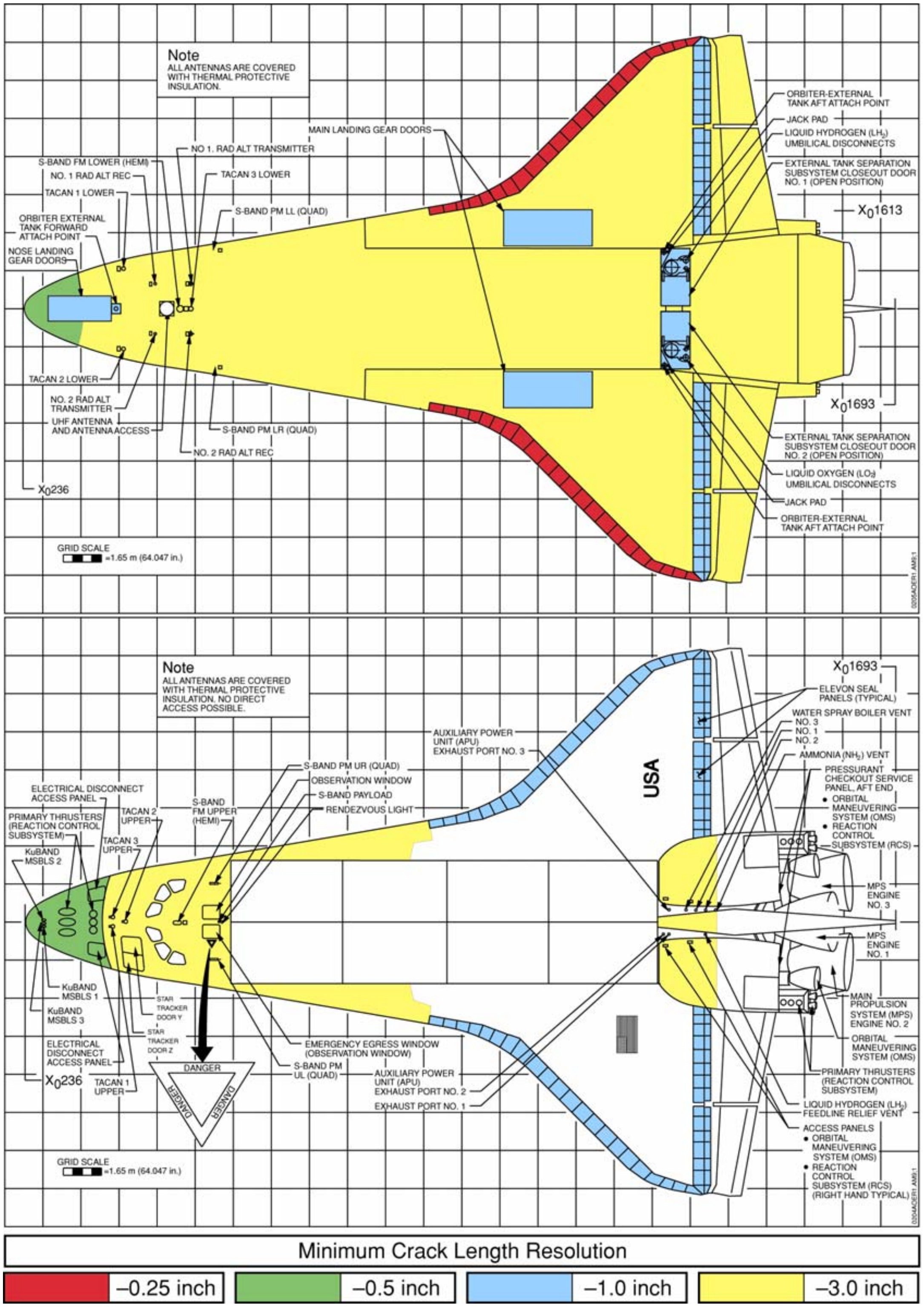


Figure 6.4-1-1. Preliminary TPS damage inspection criteria.

Boom Sensor System (OBSS) Project is currently developing a sensor system that will be flown on the first flight and used to inspect the WLE and the nose cap. The system will also be used to inspect and measure the depth of any critical TPS damage that other inspection devices, such as Station-based cameras or WLE impact sensors, have detected. The OBSS consists of sensors on the end of a boom system that is launched installed on the Orbiter's starboard sill. The boom (figure 6.4-1-2) will be used in conjunction with the SRMS to inspect the WLE RCC and nose cap prior to docking with ISS. After the Orbiter is docked to ISS, the OBSS will be used to further inspect any suspect areas on the Orbiter. In addition, the boom will have the capability to support an EVA crewmember if needed to support the inspection activities. Current plans call for the OBSS to carry a Laser Dynamic Range Imager (LDRI) sensor to detect damage to the Orbiter TPS. NASA is also developing in parallel a higher-risk, but higher-capability, Laser Camera System (LCS). NASA may choose to deploy the LCS, should the LDRI prove during operational tests to provide an insufficient level of detection for critical damage.

In February 2004, the SSP established an Inspection Tiger Team to review all inspection capabilities and to develop a plan to most effectively integrate these capabilities before return to flight. The tiger team succeeded in producing a comprehensive in-flight inspection, imagery analysis, and damage assessment strategy that will be implemented through the existing flight-planning process. The best available cameras and laser sensors suitable for detecting critical damage in each TPS zone will be used in conjunction with digital still photographs taken from ISS during the Orbiter's approach. The pitch-around maneuver required to facilitate this imagery has been developed and is pictured in figure 6.4-1-3. Shuttle crews are currently training to fly this maneuver. The tiger team strategy also laid the foundation for a more refined impact sensor and imagery system following the first two successful flights. This plan is being enhanced to clearly establish criteria for transitioning from one suite of inspection capabilities to another, and the timeline for these transitions.

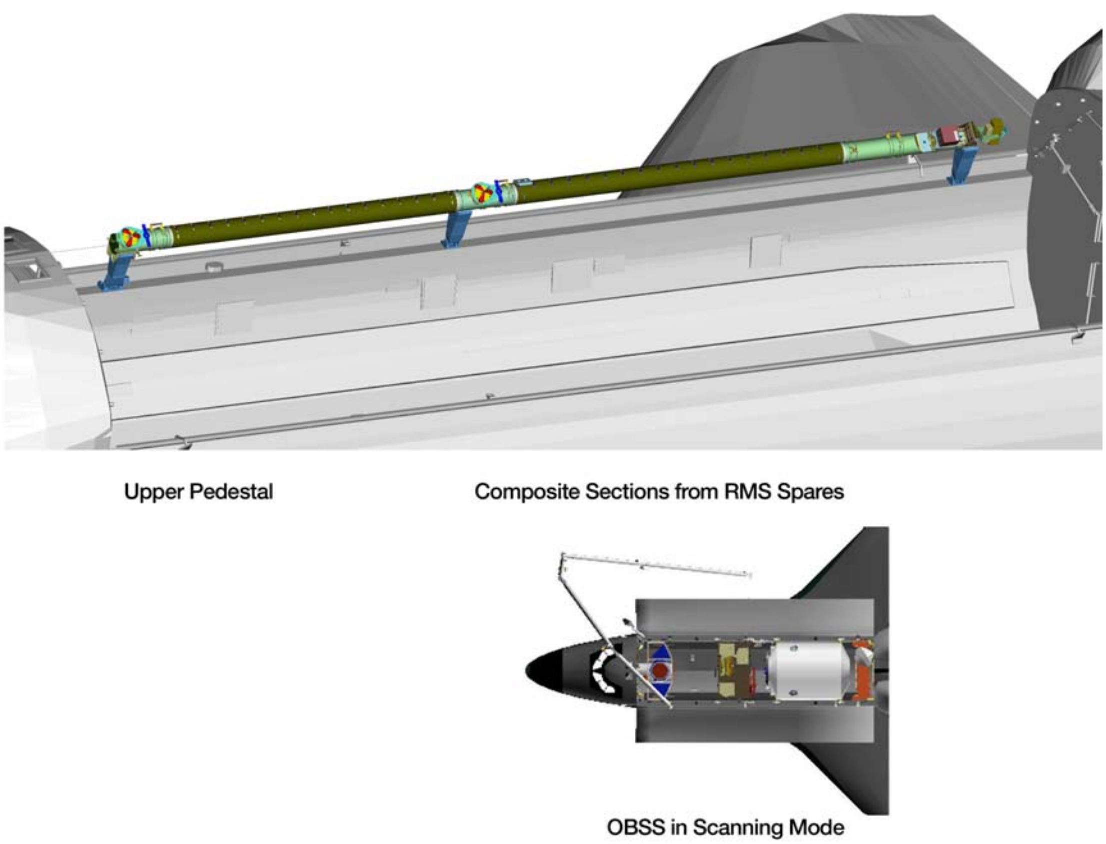
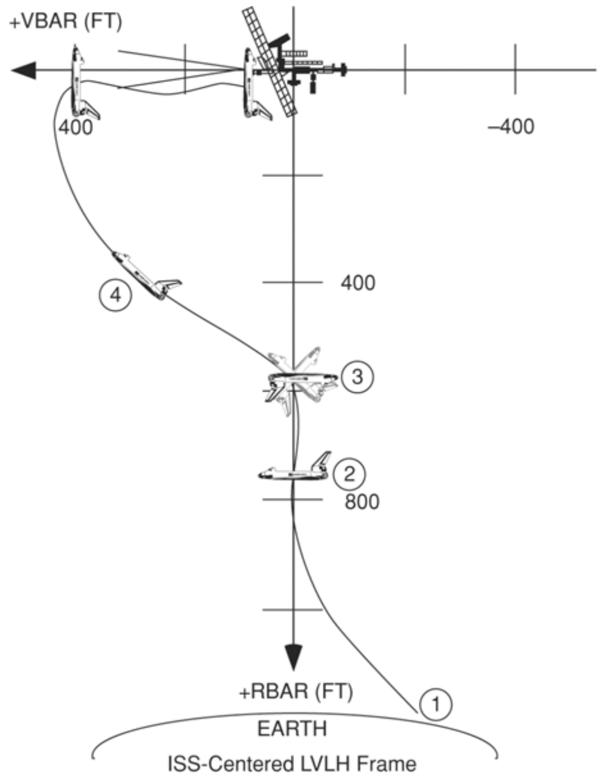


Figure 6.4-1-2. Orbiter Boom Sensor System (OBSS).



	EVENT
1	1000 FT RANGE RATE GATE (RDOT = –1.3 FPS) TRANSITION TO LOWZ
2	ORBITER ACQUIRES RBAR
3	600 FT (RDOT = –0.1 FPS BEGIN 1 DEG/SEC POSITIVE PITCH AUTO MNVR: MODE TO FREE DRIFT TO PROTECT ISS FROM ORBITER PLUME LOADS AND CONTAMINATION
	ISS PHOTOGRAPHIC SURVEY OPPORTUNITY FROM U.S. LAB WINDOW
	RESUME ATTITUDE HOLD AS ORBITER RETURNS TO RBAR ATTITUDE AND PILOT BACK TO NOMINAL APPROACH PROFILE
4	TORVA (TWICE ORBITAL RATE RBAR TO VBAR APPROACH)

Figure 6.4-1-3. Orbiter pitch-around for inspection and approach to ISS.

Along with the work of the tiger team, the Shuttle Systems Engineering and Integration Office began development of a TPS Readiness Determination Operations Concept. Most critically, this document will specify the process for collecting, analyzing, and applying the diverse inspection data in a way that ensures effective and timely mission decision-making.

Repair

TPS Repair Access

NASA has developed a combined SRMS and SSRMS "flip around" operation to allow TPS repairs while the Shuttle is docked to the ISS; this operation involves turning the Shuttle into a belly-up position that provides arm access to the repair site. As depicted in figure 6.4-1-4, the SRMS grapples the ISS while docked. The docking mechanism hooks are then opened, and the SRMS rotates the Orbiter into a position that presents the lower surface to the ISS. The EVA crew then works from the SSRMS, with the SSRMS used to position the crewmember to reach any TPS surface needing repair. After the repair, the SRMS maneuvers the Orbiter back into position and reattaches the Orbiter to the docking mechanism. This technique provides access to all TPS surfaces without the need for new equipment. The procedure will work through ISS flight 1J (which will add the Japanese Experiment Module to the ISS on orbit assembly). After ISS flight 1J, the ISS grapple fixture required to support this technique will be blocked, and new TPS repair access techniques will need to be developed.

RCC Repair

The main challenges to repairing RCC are maintaining a bond to the RCC coating during entry heating and meeting very small edge step requirements. The RCC repair project is pursuing two complementary repair concepts that together will enable repair of a range of RCC damage: Plug Repair and Crack Repair. Plug Repair consists of an insert intended to repair holes in the WLE with sizes from 0.5 in. to 4 in. in diameter. Crack Repair uses a material application intended to fill cracks and small holes in the WLE. Both concepts are expected to have limitations in terms of damage characteristics, damage location, and testing/analysis. Schedules for design, development, testing, evaluation, and production of these concepts are in work. A third repair concept, RCC rigid overwrap, encountered problems during development and was shown to be infeasible to implement in the near term; as a result, it was deleted from consideration for RTF. NASA is continuing research and development on a long-term, more flexible RCC repair technique for holes over 4 in. in diameter.

This effort is still in the concept definition phase and is much less mature than the tile repair material study. NASA is evaluating concepts across six NASA centers, 11 contractors, and the United States Air Force Research Laboratory.

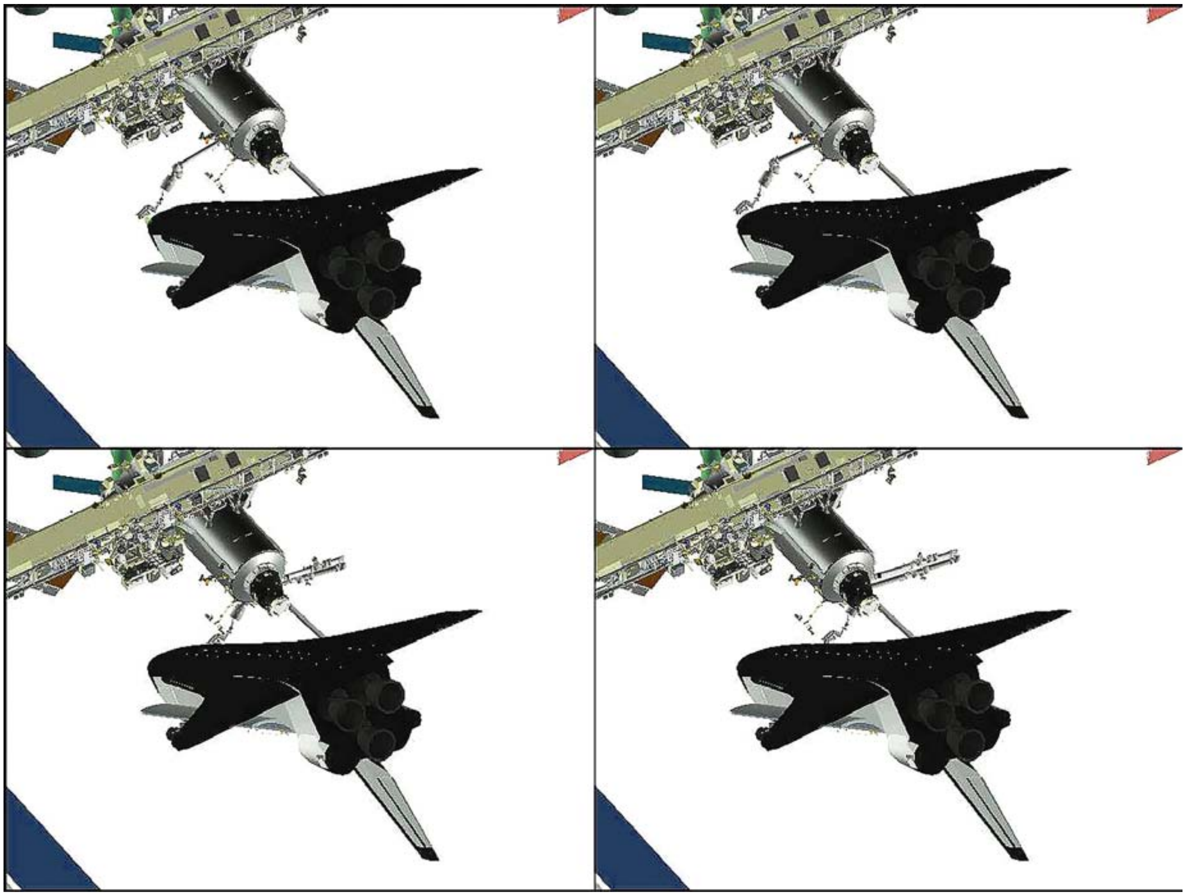


Figure 6.4-1-4. Proposed method for providing EVA access during TPS repair on an ISS flight.

Although we are aggressively pursuing RCC repair, it is too early in development to forecast a completion date.

Tile Repair

NASA has made significant progress in developing credible tile repair processes and materials. A formulation derived from an existing, silicone-based, cure-in-place ablator showed good thermal performance results in development testing in 2003. Tests confirmed that the repair material adheres to aluminum, primed aluminum, tile, strain isolation pads, and tile adhesive in vacuum and cures in vacuum. After these successful tests, NASA transitioned to characterization and qualification testing. Detailed thermal analyses and testing are under way to confirm that the material can be applied and cured in the full range of orbit conditions.

NASA is developing EVA tools and techniques for TPS repair. NASA has already developed prototype specialized tools for applying and curing tile repair materials. The lessons learned from this process will enable similar development of RCC repair tools in the future. We are also beginning to develop new and innovative EVA techniques for working with the fragile Shuttle TPS system while ensuring that crew safety is maintained. EVAs for TPS repair represent a significant challenge; the experiences gained through the numerous complex ISS construction tasks performed over the past several years are contributing to our ability to meet this challenge.

Development testing in the first half of 2004 focused on integration of the repair material with applicator hardware. During the integrated testing, instances of foaming or bubbling were experienced when the repair material was applied in a vacuum. This foaming would interfere with the repair material's ability to seal any holes found in the tile. Rigorous control of the material manufacturing process and stabilizing the applicator appears to be able to control the foaming.

Figure 6.4-1-5. Tile repair material before, during, and after arc jet testing at 2300°F.

Additional arc jet, radiant heating, thermal-vacuum, and KC-135 zero-gravity tests are scheduled to confirm that the repair material will survive the entry environment when applied using the proposed repair techniques. Assuming the continued testing of the existing ablator is successful, the tile repair materials and tools should be ready in the March 2005 timeframe. The photos in figure 6.4-1-5 show a test sample of the repair material before and after an arc jet test run to 2300°F.

Finally, NASA is developing tile repair analytical tools to support Mission Management Team decisions concerning whether or not to make a repair and to determine whether or not a repaired tile will survive entry. A significant set of wind tunnel and arc jet tests is required to satisfactorily correlate these analytical tools.

STATUS

The following actions have been completed:

- Quantified SRMS, SSRMS, and ISS digital still camera inspection resolution
- Feasibility analyses for docked repair technique using SRMS and SSRMS
- Air-bearing floor test of overall boom to SRMS interface
- OBSS conceptual development, design requirements, and preliminary design review
- Engineering assessment for lower surface radio frequency communication during EVA repair
- Simplified Aid for EVA Rescue (SAFER) technique conceptual development and testing
- Feasibility testing on tile repair material
- Tile repair material transition from concept development to validation tests
- 1-G suited tests on tile repair technique
- Initial KC-135 tile repair technique evaluations
- Vacuum dispense and cure of the tile repair material with key components of the EVA applicator
- Review of all Shuttle systems for compatibility with the docking repair scenario
- Inspection Tiger Team strategy formulated
- Down selected to two complementary RCC repair techniques for further development (Plug Repair, Crack Repair), with the elimination of Rigid Wrap Repair for RTF
- Developed the inspection and repair of the RCC and tile operations concept (figure 6.1-4-6)

Initial NASA development a third RCC repair technique, rigid overwrap, encountered significant technical challenges. As a result, the SSP recommended that the rigid wrap be deferred in favor of an expanded research and development project to develop alternative repair techniques for large holes. On June 9, 2004, the Space Flight Leadership Council approved the SSP recommendation and directed the SSP to develop plug and crack repair to the greatest extent practicable for the March 2005 launch of STS-114.

FORWARD WORK

NASA will continue to develop OBSS hardware and operational procedures.

In addition to planned TPS repair capability, special on-orbit tests are under consideration for STS-114 to further evaluate TPS repair materials, tools, and techniques.

Final detailed analyses are in work to optimize Shuttle attitude control and redocking methods during repair.

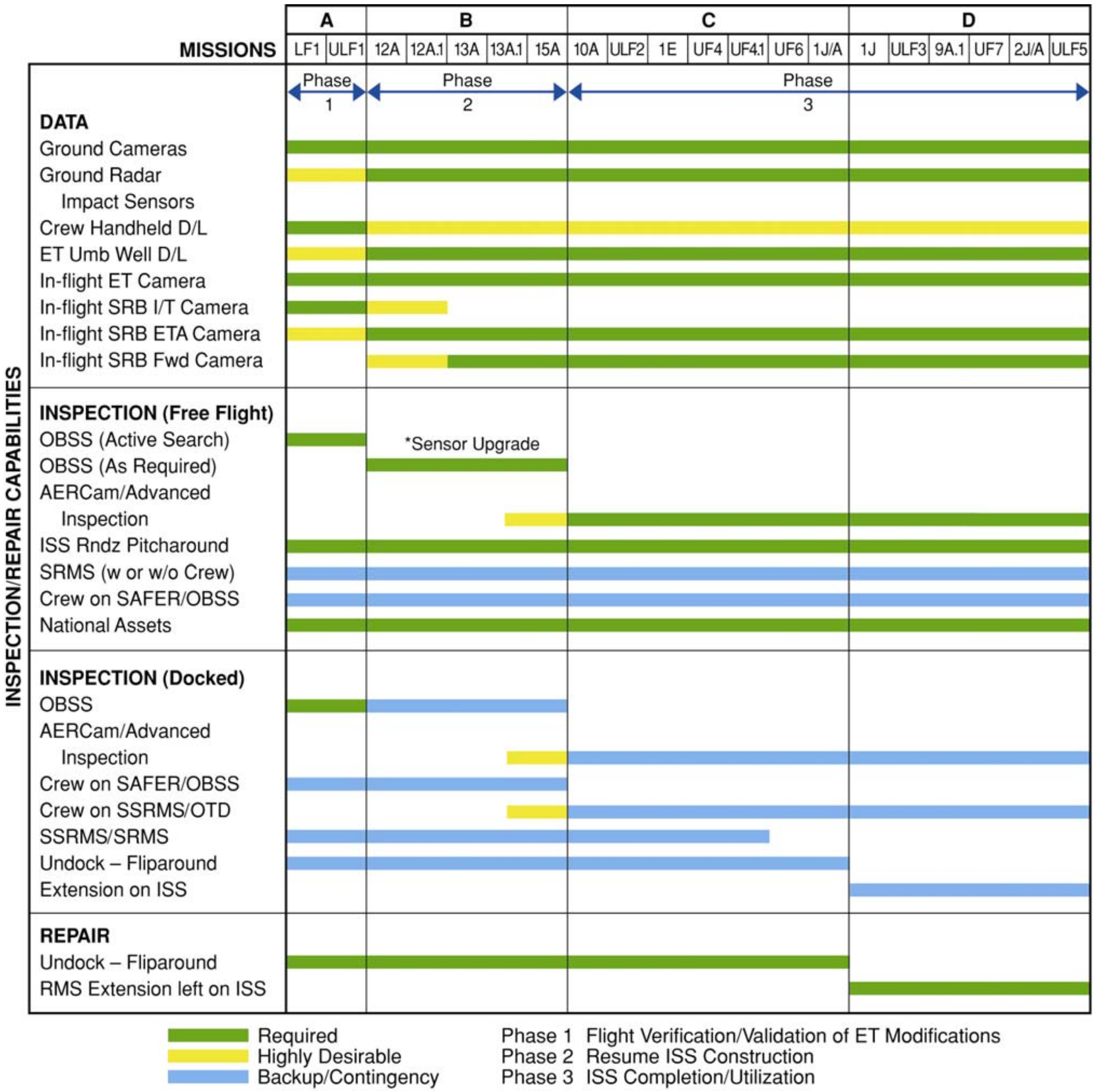


Figure 6.4-1-6. Integrated operations concepts for inspection and repair.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	1-G suited and vacuum testing begins on tile repair technique
SSP	Aug 03 (Completed)	Generic crew and flight controller training begins on inspection maneuver during approach to ISS
SSP	Aug 03 (Completed)	KC-135 testing of tile repair technique
SSP	Oct 03 (Completed)	Start of RCC repair concept screening tests
SSP	Dec 03 (Completed)	Tile repair material selection
SSP	Jun 04 (Completed)	Baseline ISS in-flight repair technique and damage criteria
JSC/Mission Operations Directorate	Aug 04	Formal procedure development complete for inspection and repair
SSP	Sep 04	Initial human thermal-vacuum, end-to-end tile repair tests
SSP ISS Program	Feb 05	All modeling and systems analyses complete for docked repair technique
SSP	TBD	Tile repair materials and tools delivery
SSP	TBD	RCC repair material selection

Columbia Accident Investigation Board

Recommendation 3.4-1

Upgrade the imaging system to be capable of providing a minimum of three useful views of the Space Shuttle from liftoff to at least Solid Rocket Booster separation, along any expected ascent azimuth. The operational status of these assets should be included in the Launch Commit Criteria for future launches. Consider using ships or aircraft to provide additional views of the Shuttle during ascent. [RTF]

BACKGROUND

NASA's evaluation of the STS-107 ascent debris impact was hampered by the lack of high-resolution, high-speed ground cameras. In response to this, tracking camera assets at the Kennedy Space Center (KSC) (figure 3.4-1-1) and on the Air Force Eastern Range will be improved to provide the best practical data during Shuttle ascent.

Multiple views of the Shuttle's ascent from varying angles and ranges provide important data for engineering assessment and discovery of unexpected anomalies. These data points are important for validating and improving Shuttle performance, but less useful for pinpointing the exact location of potential damage.

Ground cameras provide visual data suitable for detailed analysis of vehicle performance and configuration from prelaunch through Solid Rocket Booster separation. Images can be used to assess debris shed in flight, including origin, size, and trajectory. In addition to providing information about debris, the images will provide detailed information on the Shuttle systems used for trend analysis that will allow us to further improve the Shuttle. Together, these help us to identify unknown environments or technical anomalies that might pose a risk to the Shuttle.

NASA IMPLEMENTATION

NASA is developing a suite of improved ground- and airborne cameras that fully satisfies this Recommendation. This improved suite of ground cameras will maximize our ability to capture three complementary views of the Shuttle and provide the Space Shuttle Program (SSP) with engineering data to give us a better and continuing understanding of the ascent environment and the performance of the Shuttle hardware elements within this environment. Ground imagery may also allow us to detect ascent debris and identify potential damage to the Orbiter for on-orbit assessment. There are four types of imagery that NASA will acquire from the ground cameras: primary imagery—film images used as the primary analysis tools for launch and ascent operations; fall-back imagery—back-up imagery for use when the primary imagery is unavailable; quick-look imagery—imagery provided to the Image Analysis labs shortly after launch for initial assessments; and tracker imagery—images used to guide the camera tracking mounts and for analysis when needed. Any anomalous situations identified in the post-ascent "quick-look" assessments will be used to optimize the on-orbit inspections described in Recommendation 6.4-1.

NASA has increased the total number of ground cameras and added additional short-, medium-, and long-range camera sites, including nine new quick-look locations.

Figure 3.4-1-1. Typical KSC long-range tracker.

Since all future Shuttle missions are planned to the International Space Station, the locations of the new cameras and trackers are optimized for 51.6-degree-inclination launches. Previously, camera coverage was limited by a generic configuration originally designed for the full range of possible launch inclinations and ascent tracks. NASA has also added Standard Definition Television (SDTV) serial digital cameras and 35mm and 16 mm motion picture cameras for quick-look and fall-back imagery, respectively. In addition, NASA has taken steps to improve the underlying infrastructure for distributing and analyzing the additional photo imagery obtained from ground cameras. Some of this infrastructure is built on the system configured to support the distribution and images and engineering data in support of the *Columbia* accident investigation.

System Configuration

NASA divides the Shuttle ascent into three overlapping periods with different imaging requirements. These time periods provide for steps in lens focal lengths to improve image resolution as the vehicle moves away from each camera location:

- Short-range images (T-10 seconds through T+57 seconds)
- Medium-range images (T-7 seconds through T+100 seconds)
- Long-range trackers (T-7 or vehicle acquisition through T+165 seconds)

For short-range imaging, NASA has two Photographic Optic Control Systems (POCS) to control the fixed-film cameras at the launch pad, Shuttle Landing Facility, and the remote areas of KSC. There is significant redundancy in this system: each POCS has the capability of controlling up to 512 individual cameras at a rate of 400 frames per second. Currently, there are approximately 50 cameras positioned for launch photography. POCS redundancy is also provided by multiple sets of command and control hardware and by multiple overlapping views, rather than through back-up cameras. The POCS are a part of the Expanded Photographic Optic Control Center (EPOCC). EPOCC is the hub for the ground camera system.

The medium- and long-range tracking devices will be on mobile Kineto Tracking Mount (KTM) platforms, allowing them to be positioned optimally for each flight. The two trackers on the launch pad will be controlled with the Pad Tracker System (PTS). PTS is a KSC-designed and -built system that provides both film and video imagery. It has multiple sets of command and control hardware to provide system redundancy. Each of the medium- and long-range tracking cameras is independent, assuring that no single failure can disable all of the trackers. Further, each of the film cameras on the trackers has a back up. For each flight, NASA will optimize the camera configuration, evaluating the locations of the cameras to ensure that the images provide the necessary resolution and coverage. NASA will be adding a third tracker site prior to return to flight (RTF).

The locations at Launch Complex 39-B for short-range, medium-range, and long-range tracking cameras are as shown in figures 3.4-1-2, 3.4-1-3, and 3.4-1.4, respectively. Existing cameras will be moved, modernized, and augmented to comply with new requirements.

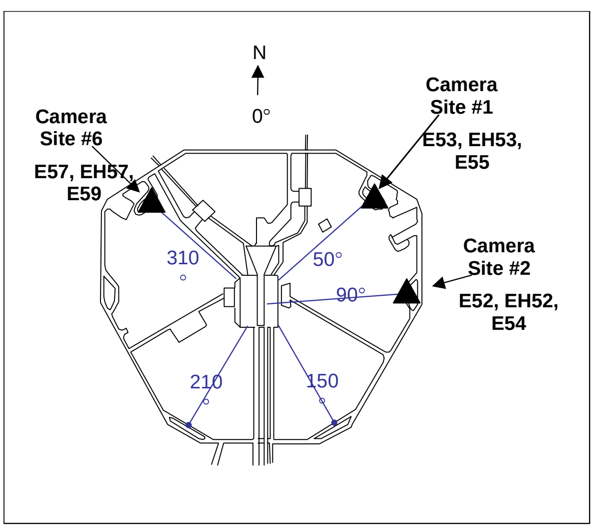


Figure 3.4-1-2. Short-range camera sites.

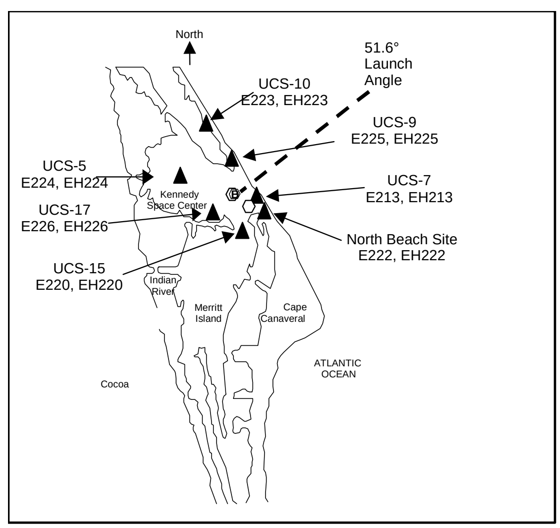


Figure 3.4-1-3. Medium-range tracker sites.

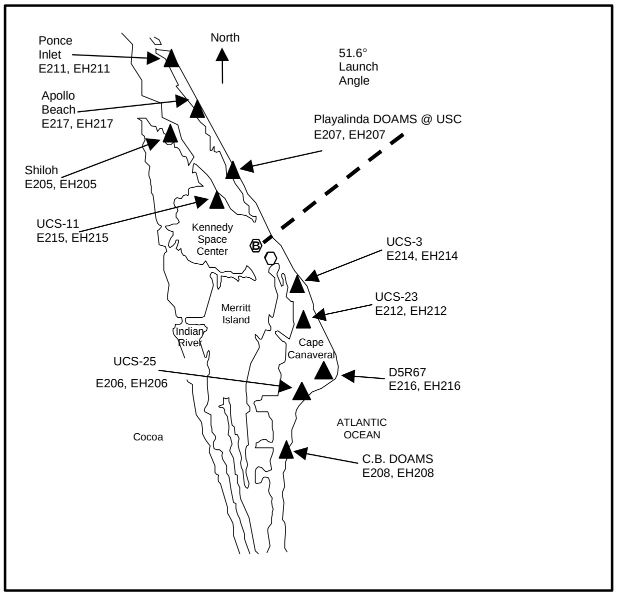


Figure 3.4-1-4. Long-range tracker sites.

Figure 3.4-1-5. WB-57 aircraft.

In addition to ground cameras, NASA has approved the development and implementation of an aircraft-based imaging system known as the WB-57 Ascent Video Experiment (WAVE) to provide both ascent and entry imagery. The use of an airborne imaging system will provide opportunities to better observe the vehicle during days of heavier cloud cover and in areas obscured from ground cameras by the exhaust plume following launch.

The primary hardware for the WAVE consists of a 32-in. ball turret system mounted on the nose of two WB-57 aircraft (figure 3.4-1-5). The use of two aircraft flying at an altitude of 60,000 ft will allow a wide range of coverage with each airplane providing imagery over a 400-mi path. The entry imaging program will involve the use of a Navy P3 aircraft to provide imagery during the later stages of entry. The WAVE ball turret houses an optical bench that provides a location for installation of multiple camera systems (High-Definition Television (HDTV), infrared). The optics consists of a 5-m fixed focal length lens with an 11-in. diameter, and the system can be operated in both auto track and manual modes.

WAVE will be used on an experimental basis during the first two Space Shuttle flights following RTF. Based on an analysis of the system's performance and quality of the products obtained, following these two flights NASA will make the decision on whether to continue use of this system on future flights. The Critical Design Review for the WAVE was completed on July 1, 2004.

Although the ground cameras provide important engineering data for the Shuttle, they cannot have the resolution and coverage necessary to definitively establish that the Orbiter has suffered no ascent debris damage. No real-time decisions will be based on ground imagery data. Rather, the comprehensive assessments of Orbiter impacts and damage necessary to ensure the safety of the vehicle and crew will be conducted using on-orbit inspection and analysis.

NASA's analysis suggests that this upgraded suite of ground and airborne cameras will significantly improve NASA's ability to obtain three useful views of each Shuttle launch, particularly in conditions of limited cloud cover.

Launch Requirements

NASA is optimizing our launch requirements and procedures to support our ability to capture three complementary views of the Shuttle, allowing us to conduct engineering analysis of the ascent environment. Initially, NASA will launch in daylight to maximize our ability to capture the most useful ground ascent imagery. Camera and tracker operability and readiness to support launch will be ensured by a new set of pre-launch equipment and data system checks that will be conducted in the 48 hours prior to liftoff. These checkouts will be documented in the Operations and Maintenance Requirements and Specifications Document. In addition, specific launch commit criteria (LCC) have been added for those critical control systems and data collection nodes for which a failure would prevent the operation of multiple cameras or disrupt our ability to collect and analyze the data in a timely fashion. The final camera LCC will be tracked to the T-9 minute milestone, and the countdown will not be continued if the criteria are not satisfied.

With the additional cameras and trackers that will be available at RTF, NASA has provided sufficient redundancy in the system to allow us to gather ample data and maintain three useful views—even with the loss of an individual camera or tracker. As a result, it is not necessary to track the status of each individual camera and tracker after the final operability checks. This enhances overall Shuttle safety by removing an unnecessary item for status tracking during the critical terminal countdown, allowing the Launch Control Team to concentrate on the many remaining key safety parameters. The LCCs remaining until the T-9 minute milestone protect the critical control systems and data collection nodes whose failure might prevent us from obtaining the engineering data necessary to assess vehicle health and function during ascent. For instance, the LCC will require that at least one POCS be functional at T-9 minutes, and that the overall system be stable and operating.

NASA has also confirmed that the existing LCCs related to weather constraints dictated by Eastern Range safety meet support camera coverage requirements. NASA conducted detailed meteorological studies using Cape weather histories, which concluded that current Shuttle launch weather requirements also adequately protect against the possibility that multiple camera views could be obscured by clouds. The wide geographic area covered by the ground camera suite and the cameras added in the post-*Columbia* refurbishment help to ensure that weather does not interfere with our ability to capture three useful views of the Shuttle during ascent. The weather LCCs balance launch probability, including the need to avoid potentially dangerous launch aborts, against the need to have adequate camera coverage of ascent. The extensive revitalization of the ground camera system accomplished since the *Columbia* accident provides the redundancy that makes such an approach viable and appropriate.

STATUS

The Program Requirements Control Board (PRCB) approved an integrated suite of imagery assets that will provide the SSP with the engineering data necessary to validate the performance of the External Tank (ET) and other Shuttle systems, detect ascent debris, and identify and characterize damage to the Orbiter. On August 12, 2004, the PRCB approved funding for the camera suite, to include procurement and sustaining operations. The decision package included the deletion of several long- and medium-range cameras after the first two re-flights, contingent on clearing the ET and understanding the ascent debris environment.

NASA has begun shipping the 14 existing trackers to the vendor for refurbishment. This work will be ongoing until refurbishment of all trackers is complete in 2006. Trackers and optics will be borrowed from other ranges to support launches until the refurbished assets are delivered. NASA has also approved funding to procure additional spare mounts, as well as to fund studies on additional capability in the areas of infrared and ultraviolet imagery, adaptive optics, and high-speed digital video, and in the rapid transmission of large data files for engineering analysis.

NASA has doubled the total number of camera sites from 10 to 20, each with two or more cameras. At RTF, NASA will have three short-range camera sites around the perimeter of the launch pad; seven medium-range camera sites; and 10 long-range camera sites. To accommodate the enhanced imagery, we will install high-volume data lines for rapid image distribution and improve KSC's image analysis capabilities.

NASA is also procuring additional cameras to provide increased redundancy and refurbishing existing cameras. NASA has ordered 78 fixed camera lenses to supplement the existing inventory and has purchased two KTM Digital Signal Processing Amplifiers to improve KTM reliability and performance. In addition, NASA has received 24 Serial Digital interface cameras to improve our quick-look capabilities.

The U.S. Air Force-owned optics for the Cocoa Beach, Florida, camera (the "fuzzy camera" on STS-107) have been returned to the vendor for repair. We have completed an evaluation on current and additional camera locations, and refined the requirements for camera sites. Additional sites have been picked and are documented in the Launch and Landing Program Requirements Document 2000, sections 2800 and 3120. Additional operator training will be provided to improve tracking, especially in difficult weather conditions.

NASA is on track to implement the WAVE airborne camera systems to provide both ascent and entry imagery for RTF.

NASA's plan for use of ground-based wideband radar and ship-based Doppler radar to track ascent debris is addressed in Part 2 of this document under item SSP-12, Radar Coverage Capabilities and Requirements.

FORWARD WORK

The SSP is addressing hardware upgrades, operator training, and quality assurance of ground-based cameras according to the integrated imagery requirements assessment.

Prior to RTF, NASA will add redundant power sources to the command and control facility as part of our Ground Camera Upgrade to ensure greater redundancy in the fixed medium-/long-range camera system. NASA is also adding a third KTM site prior to RTF.

NASA will continue to study improvements to its ground imagery capabilities following RTF. Additional enhancements may include replacing the SDTV and motion picture film cameras with HDTV cameras and improving our image distribution and analysis capabilities to accommodate the HDTV content.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Completed)	Program Approval of Ground Camera Upgrade Plan
SSP	Sep 03 (Completed)	Program Approval of funding for Ground Camera Upgrade Plan
SSP	Feb 04 (Completed)	Baseline Program Requirements Document Requirements for additional camera locations
SSP	May 04 (Completed)	Begin refurbishment of 14 existing trackers. Will be ongoing until all refurbishment of all trackers is complete (expected 2006) Trackers and optics will be borrowed from other ranges to support launch until the assets are delivered
SSP	Jul 04 (Completed)	Critical Design Review for WAVE airborne imaging system
SSP	Aug 04	Baseline revised Launch Commit Criteria
SSP	Feb 05	Install new optics and cameras
SSP	Mar 05	Acquire six additional trackers, optics, cameras, and spares for all systems. Trackers will be borrowed from other ranges to support launches until the vendor delivers the new KSC trackers

Columbia Accident Investigation Board

Recommendation 3.4-2

Provide a capability to obtain and downlink high-resolution images of the External Tank after it separates. [RTF]

BACKGROUND

NASA agrees that it is critical to verify the performance of the External Tank (ET) modifications to eliminate ascent debris. Real-time downlink of this information may help in the early identification of some risks to flight. The Space Shuttle currently has two on-board high-resolution cameras that photograph the ET after separation; however, the images from these cameras are available only postflight and are not downlinked to the Mission Control Center during the mission. Therefore, no real-time imaging of the ET is currently available to provide engineering insight into potential debris during the mission.

NASA IMPLEMENTATION

To provide the capability to downlink images of the ET after separation for analysis, NASA is replacing the 35mm film camera in the Orbiter umbilical well with a high-resolution digital camera and equipping the flight crew with a handheld digital still camera with a telephoto lens. Umbilical and handheld camera images will be downlinked after safe orbit operations are established. These images will be used for quick-look analysis by the Mission Management Team to determine whether any ET anomalies exist that require additional on-orbit inspections (see Recommendation 6.4-1).

STATUS

The Space Shuttle Program (SSP) Requirements Control Board approved the Orbiter Project plan for installing the new digital camera in the Orbiter umbilical well for STS-114. NASA is completing test and verification of the performance of the new digital camera for the ET umbilical well. Based on results and analysis to date, NASA anticipates that the new umbilical well camera (figure 3.4-2-1) can be installed before return to flight. Orbiter design engineering and modifications to provide this capability are under way on all three vehicles.

FORWARD WORK

NASA will complete functional testing of the new digital camera in September 2004. The Orbiter umbilical well camera will be installed beginning in January 2005.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Sep 03 (Completed)	Initiate Orbiter umbilical well feasibility study
SSP	Apr 04 (Completed)	Complete preliminary design review/critical design review on approved hardware
SSP	May 04 (in progress)	Begin Orbiter umbilical well camera wiring and support structure installation
SSP	Sep 04	Begin system functional testing
SSP	Jan 05	Install digital umbilical well camera

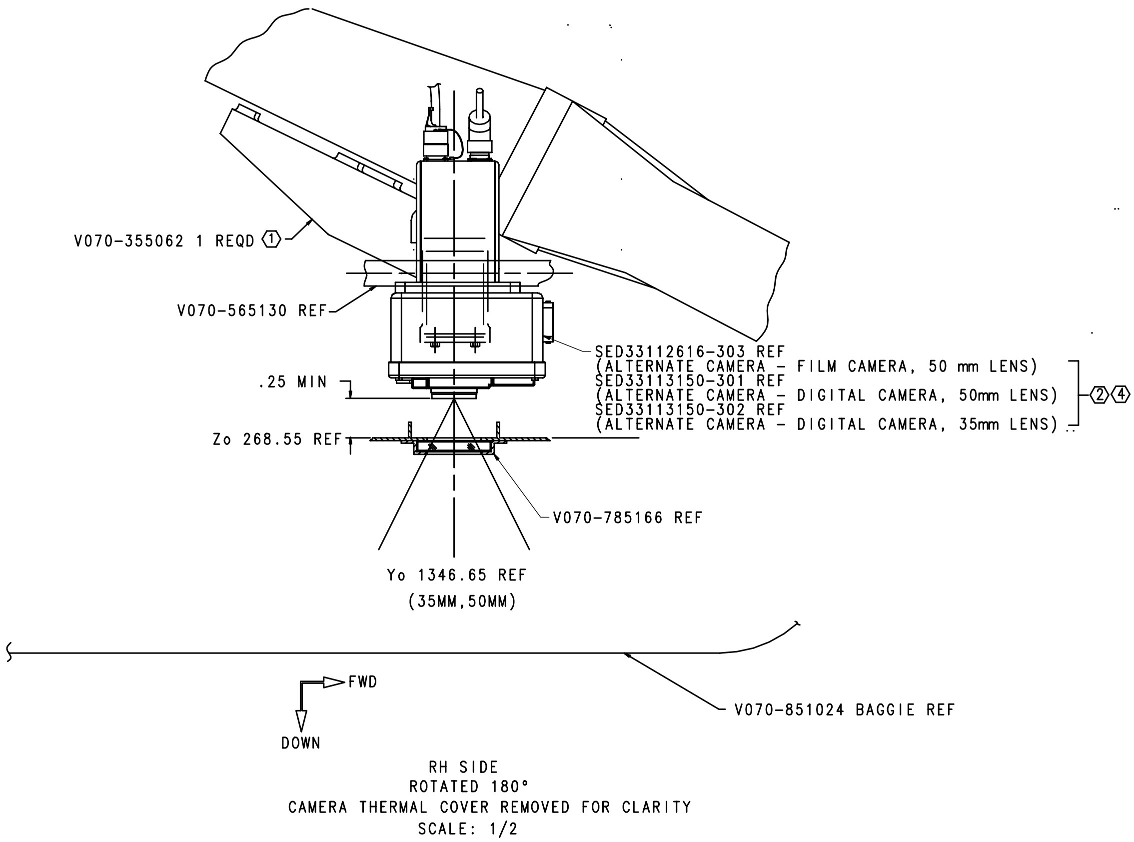


Figure 3.4-2-1. Schematic of umbilical well camera.

Columbia Accident Investigation Board

Recommendation 3.4-3

Provide a capability to obtain and downlink high-resolution images of the underside of the Orbiter wing leading edge and forward section of both wings' Thermal Protection System. [RTF]

BACKGROUND

The damage to the left wing of *Columbia* occurred shortly after liftoff, but went undetected for the entire mission. Although there was ground photographic evidence of debris impact, we were unaware of the extent of the damage. Therefore, NASA is adding on-vehicle cameras and sensors that will help to detect and assess damage.

NASA IMPLEMENTATION

For the first few missions after return to flight, NASA will use primarily on-orbit inspections to meet the requirement to assess the health and status of the Orbiter's Thermal Protection System. Details on our on-orbit inspections can be found in Recommendation 6.4-1. On-vehicle ascent imagery will be a valuable source of engineering, performance, and environments data and will be useful for understanding in-flight anomalies. This on-vehicle ascent imagery suite does not provide complete imagery of the underside of the Orbiter or guarantee detection of all potential impacts to the Orbiter. NASA's long-term strategy will include improving on-vehicle ascent imagery and the addition of an impact detection sensor system on the Orbiter. Once NASA has confidence in the redesigned External Tank's (ET's) performance, we may choose to rely more heavily on ascent imagery in place of higher risk, crew-time intensive on-orbit imagery techniques.

Ascent Imagery

For STS-114, NASA will have cameras on the ET-liquid oxygen (LO_2) feedline fairing and the Solid Rocket Booster (SRB)-forward skirt ET inter-tank area. These assets are referred to as the Enhanced Launch Vehicle Imaging System (ELVIS). ELVIS is designed to provide imagery for use in the engineering evaluation of the general condition of the Shuttle and the performance of specific Shuttle components. It will also allow NASA to track debris during launch and ascent to determine whether debris allowables have been violated. However, most of the cameras will be operating at 30 frames per second, which will limit the clarity of some images.

The ET-LO_2 feedline fairing camera will take images of the ET bipod areas and the underside of the Shuttle fuselage and the right wing from liftoff through the first 15 minutes of flight. The camera's prime focus, however, will be on the first stage of flight when the majority of ascent debris has the potential to be liberated. These images will be transmitted real time to ground stations. The new location of the ET camera will reduce the likelihood that its views will be obscured by the Booster Separation Module plume, a discrepancy observed on STS-112.

The SRB forward skirt cameras will take images from three seconds to 350 seconds after liftoff. These two cameras will look sideways into the ET intertank. The images from this location will be stored on the SRBs and available after the SRBs are recovered, approximately three days after launch.

Beginning with STS-115, we will introduce an additional complement of cameras on the SRBs: aft-looking cameras located on the SRB forward skirt and forward-looking cameras located on the SRB External Tank Attachment (ETA) Ring. Together, these additional cameras will provide comprehensive views Orbiter's underside during ascent.

STATUS

The Program Requirements Control Board approved the Level II requirements for ELVIS; the system will be implemented for return to flight.

FORWARD WORK

NASA will continue to research options to improve camera resolution, functionality in reduced lighting conditions, and alternate camera mounting configurations. In the meantime, work is proceeding on the new SRB camera designs and implementation of the approved ET and SRB cameras and wing leading edge sensors.

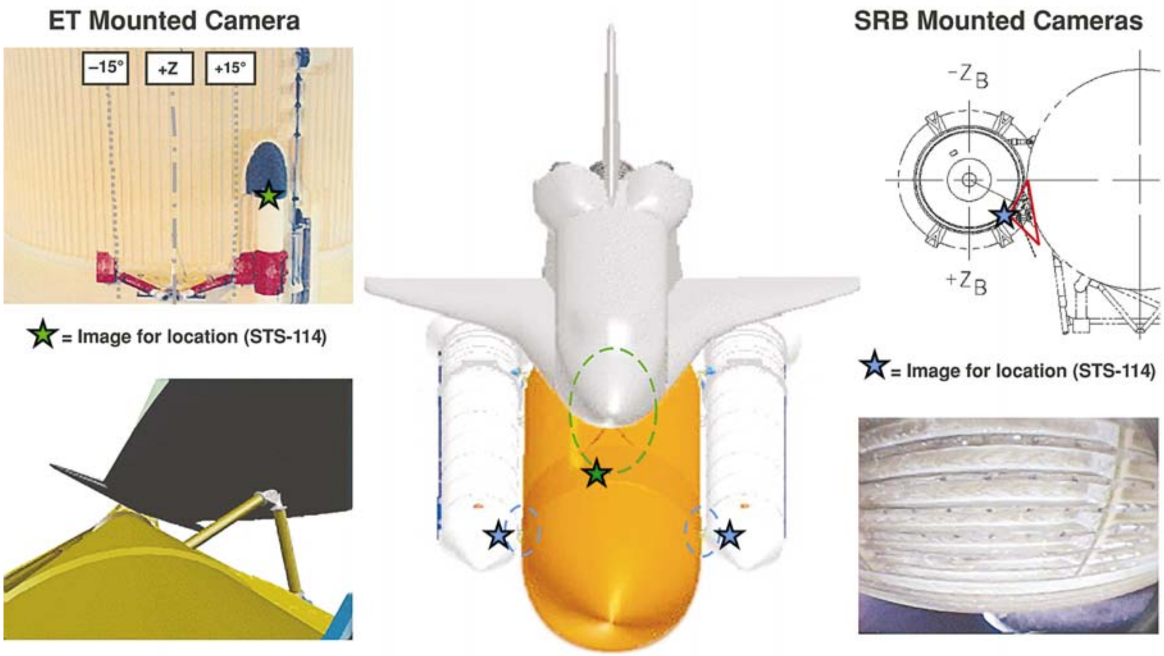


Figure 3.4-3-1. ET flight cameras (STS-114 configuration).

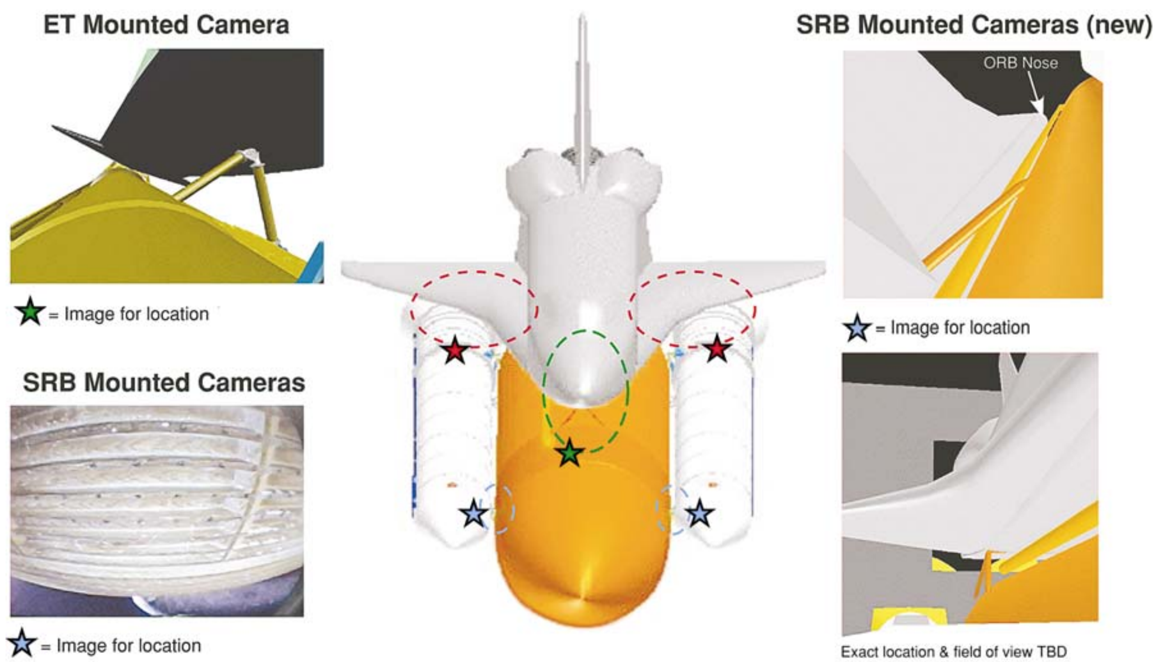


Figure 3.4-3-2. ET flight cameras (TBD configuration).

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	May 03 (Completed)	Start ET hardware modifications
SSP	Jul 03 (Completed)	Authority to proceed with ET LO_2 feedline and SRB forward skirt locations; implementation approval for ET camera
SSP	Mar 04 (Completed)	Systems Requirements Review
SSP	Jun 04 (Completed)	Begin ET camera installations
SSP	Sep 04	Begin SRB “ET Observation” camera installation
SSP	Mar 05	Review SRB camera enhancements for mission effectivity

Columbia Accident Investigation Board
Recommendation 3.6-2

The Modular Auxiliary Data System should be redesigned to include engineering performance and vehicle health information and have the ability to be reconfigured during flight in order to allow certain data to be recorded, telemetered, or both, as needs change.

BACKGROUND

The Modular Auxiliary Data System (MADS)* provides limited engineering performance and vehicle health information postflight. There are two aspects to this recommendation: (1) redesign for additional sensor information, and (2) redesign to provide the ability to select certain data to be recorded and/or telemetered to the ground during the mission. To meet these recommendations, a new system must be developed to replace MADS. The evaluation of this replacement is currently in progress to address system obsolescence issues and also provide additional capability.

Requirements are being baselined for the Vehicle Health Monitoring System (VHMS), which is being developed to replace the existing MADS with an all-digital industry standard instrumentation system. VHMS will provide increased capability to enable easier addition of sensors that will lead to significant improvements in monitoring vehicle health.

NASA IMPLEMENTATION

The VHMS Project will provide the capability to collect, condition, sample, time-tag, and store all sensor data. The collected data can be downlinked to the ground during flight operations or archived for download after landing. The VHMS will also allow the addition of other sensor data and instrumentation systems.

STATUS

The VHMS Project has successfully baselined the systems requirements for the Digital MADS (DMADS), which will replace the existing MADS. The systems requirements for modifying the existing Mass Memory Unit have also been baselined to include additional capability for increased data inputs and memory for data storage.

The VHMS Project gained Program Requirements Control Board (PRCB) approval to evaluate the addition of payload bay accelerometers to Orbiter Vehicle (OV)-104 for STS-121. These accelerometers are currently installed on OV-103 and will be active for STS-114. To improve data collection ability in the short term until the availability of the DMADS, the PRCB also approved connecting the MADS Pulse Code Modulation Unit to the solid-state recorder to provide on-orbit downlink of additional low-rate MADS ascent data. This will increase NASA's ability to access data during missions.

NASA completed its evaluation of contractor proposals and has selected a vendor for the DMADS.

FORWARD WORK

The Space Shuttle Program (SSP) will continue VHMS Project requirements reviews and implementation plans, and will provide status updates to the PRCB.

*Note that the *Columbia* Accident Investigation Board Report alternately refers to this as the OEX Recorder.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Completed)	VHMS Program Requirements Review
SSP	Oct 03 (Completed)	VHMS Program Requirements Document baselined at Space Shuttle Upgrades PRCB
SSP	Jan 04 (Completed)	Mass Memory Unit-Retrofit (MMU-R) System Requirements Document baselined
SSP	Mar 04 (Completed)	MMU-R System Requirements Review
SSP	Apr 04 (Completed)	DMADS Systems Requirements Review
SSP	May 04 (Completed)	DMADS Systems Requirements Document baselined
SSP	Jun 04 (Completed)	MMU-R Systems Design Review
SSP	Jul 04 (Completed)	DMADS proposal evaluation and vendor selection
SSP	Aug 04	DMADS Systems Design Review
SSP	Sep 04	MMU-R Preliminary Design Review
SSP	Jan 05	DMADS Preliminary Design Review

Columbia Accident Investigation Board

Recommendation 4.2-2

As part of the Shuttle Service Life Extension Program and potential 40-year service life, develop a state-of-the-art means to inspect all Orbiter wiring, including that which is inaccessible.

Note: With the establishment of a new national policy for U.S. space exploration in January 2004, the planned service life of the Space Shuttle was reduced. Following its return to flight, the Space Shuttle will be used to complete assembly of the International Space Station, planned for the end of the decade, and then the Shuttle will be retired. Due to the reduced service life, NASA's approach to complying with this recommendation has been appropriately adjusted. These actions were closed through the formal Program Requirements Control Board (PRCB) process. The following summary details NASA's response to the recommendation and any additional work NASA intends to perform beyond the *Columbia* Accident Investigation Board recommendation.

BACKGROUND

A significant amount of Orbiter wiring is insulated with Kapton, a polyimide film used as electrical insulation. Kapton-insulated wire has many advantages; however, over the years several concerns have been identified and addressed by the Space Shuttle Program (SSP) through both remedial and corrective actions.

Arc tracking, one of these ongoing concerns, was highlighted during STS-93 as a result of a short circuit in the wiring powering one of the channels of the Space Shuttle Main Engine controllers. Arc tracking is a known failure mode of Kapton wiring in which the electrical short can propagate along the wire and to adjacent wiring. Following STS-93, NASA initiated an extensive wiring investigation program to identify and replace discrepant wiring. NASA also initiated a program of Critical Wire Separation efforts. This program separated redundant critical function wires that were colocated in a single wire bundle into separate wire bundles to mitigate the risk of an electrical short on one wire arc tracking to an adjacent wire and resulting in the total loss of a system. In areas where complete separation was not possible, inspections are being performed to identify discrepant wire and to protect against damage that may lead to arc tracking. In addition, abrasion protection (convoluted tubing) is being added to wire bundles that carry circuits of specific concern and/or are routed through areas of known high damage potential.

The STS-93 wiring investigation also led to improvements in the requirements for wiring inspections, wiring inspection techniques, and wire awareness training of personnel working in the vehicle. Wiring was inspected, separated, and protected in the accessible areas during the general flight-to-flight Operations and Maintenance Requirements Specification Document (OMRSD) process. The wiring that was inaccessible during the OMRSD process was inspected, separated, and protected during the Orbiter Maintenance Down Period.

Currently, visual inspection is the most effective means of detecting wire damage. Technology-assisted techniques such as Hipot, a high-potential dielectric verification test, and time domain reflectometry (TDR), a test that identifies changes in the impedance between conductors, are rarely effective for detecting damage that does not expose the conductor or where a subtle impedance change is present. Neither is an effective method for detecting subtle damage to wiring insulation. However, for some areas, visual inspection is impractical. The Orbiters contain some wire runs, such as those installed beneath the crew module, that are completely inaccessible to inspectors during routine ground processing. Even where wire is installed in accessible areas, not every wire segment is available for inspection due to bundling and routing techniques. In these areas, NASA will depend on technology-assisted inspection techniques to detect damage.

NASA IMPLEMENTATION

NASA took a broad approach to mitigating Orbiter wiring concerns by developing promising new technologies and partnering with other government agencies. The SSP also improved its current inspection and repair techniques. Additionally, the Program evaluated other wire insulation types, identified inaccessible wiring, and developed a potential wire replacement methodology.

At Ames Research Center, engineers developed the proposed Hybrid Reflectometer, a TDR derivative. The goals of this development are to mature TDR technologies (including hardware and software) for more sensitive wire insulation defect detection and to assess packaging the system into a device for operational use in the Orbiter. At Langley Research Center (LaRC), engineers are developing a wire insulation age-life tester. Potential technologies for this application include ultrasonic and infrared spectroscopy. Additionally, LaRC engineers are developing an ultrasonic crimp joint tool to measure the integrity of wire crimps as they are made. At Johnson Space Center, engineers are developing a destructive age-life test capability.

The problem of aging wiring is not unique to NASA or the SSP. Military and civilian aircraft are also frequently used beyond their original design lives. As a result, continual research is conducted to safely extend the life of these aircraft and their systems. NASA will partner with industry, academia, and other government agencies to find the most effective means to address these concerns. For example, NASA will continue to participate in the Joint Council for Aging Aircraft and collaborate with the Air Force Research Laboratory.

STATUS

On June 17, 2004, the PRCB approved a comprehensive plan for assuring the health of Orbiter wiring for the remaining life of the Program. This plan emphasizes remedial actions that build upon the wiring damage corrective measures that have been in place since the post STS-93 wiring effort. NASA will also expand its wiring destructive evaluation program to better characterize the specific vulnerabilities of Orbiter wiring to aging and damage, and to predict future wiring failures, especially in inaccessible areas.

To formalize these improvements, NASA revised Specification ML0303-0014, "Installation Requirements for Electrical Wire Harnesses and Coaxial Cables," with improved guidelines for wire inspection procedures and protection protocols. A new Avionics Damage Database has also been implemented to capture statistical data that will improve NASA's ability to analyze and predict wiring damage trends. NASA has initiated an aggressive wire damage awareness program that will limit the number of people given access to areas in the Orbiter where wiring can be damaged. In addition, training will be given to personnel who require entry to areas that have a high potential for wiring damage. This training will help raise awareness and reduce unintended processing damage.

To improve our understanding of wiring issues, information and technical exchanges will continue between the SSP, NASA research centers, and other agencies dealing with aging wiring issues, such as the Federal Aviation Administration and the Department of Defense. If these research efforts yield a technically mature nondestructive inspection technique for wiring, the SSP will evaluate incorporating that technique into vehicle processing and inspection protocols. However, as technical readiness levels for nondestructive wiring inspection appear unlikely to mature before the planned retirement of the Shuttle, the SSP will emphasize mitigating aging wiring risk through the design changes and procedural controls discussed above.

The SSP will implement its aging/damaged wiring risk mitigation plan to maximize safety improvements within the constraints of current technical capabilities and given the Shuttle's planned retirement at the end of the decade.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Apr 04 (Completed)	Present project plan to the Program Requirements Control Board

Columbia Accident Investigation Board
Recommendation 4.2-1

Test and qualify the flight hardware bolt catchers. [RTF]

BACKGROUND

The External Tank (ET) is attached to the Solid Rocket Boosters (SRBs) at the forward skirt thrust fitting by the forward separation bolt. The pyrotechnic bolt is actuated at SRB separation by fracturing the bolt in half at a predetermined groove, releasing the SRBs from the ET thrust fittings. The bolt catcher attached to the ET fitting retains the forward half of the separation bolt. The other half of the separation bolt is retained within a cavity in the forward skirt thrust post (figure 4.2-1-1).

The STS-107 bolt catcher design consisted of an aluminum dome welded to a machined aluminum base bolted to both the left- and right-hand ET fittings. The inside of the bolt catcher was filled with a honeycomb energy absorber to decelerate the ET half of the separation bolt (figure 4.2-1-2).

Static and dynamic testing demonstrated that the manufactured lot of bolt catchers that flew on STS-107 had a factor of safety of approximately 1. The factor of safety for the bolt catcher assembly should be 1.4.

NASA IMPLEMENTATION

The new bolt catcher assembly and related hardware will be designed and qualified by testing as a complete system to demonstrate compliance with factor-of-safety requirements. The bolt catcher housing will be fabricated from a single piece of aluminum forging (figure 4.2-1-3) that removes the weld from the original design (figure 4.2-1-4). Further, a new energy-absorbing material will be selected, the thermal protection material is being reassessed (figure 4.2-1-5), and the ET attachment bolts and inserts (figure 4.2-1-6) are being redesigned and resized.

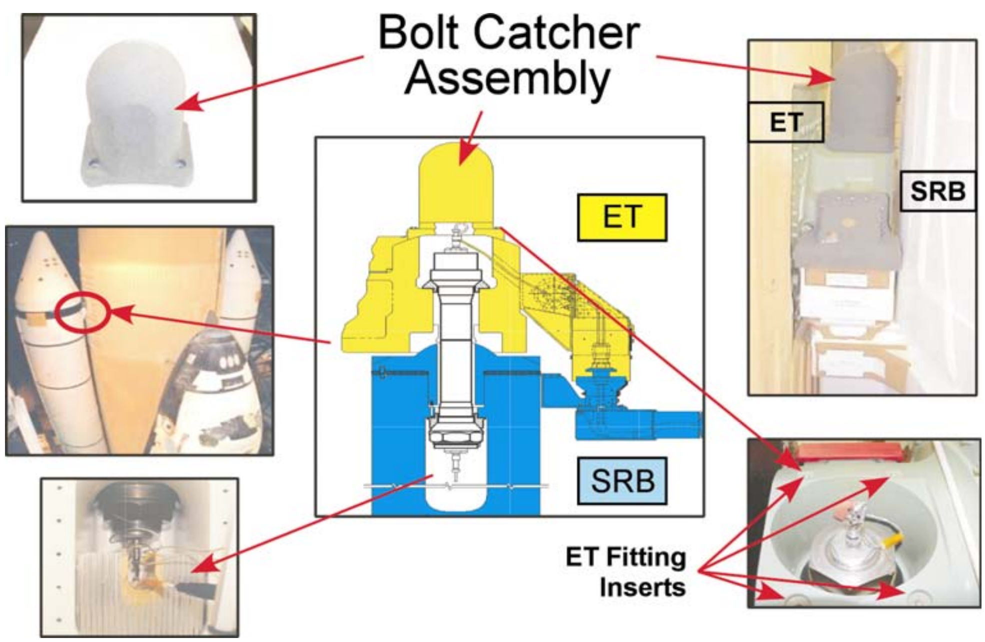


Figure 4.2-1-1. SRB/ET forward attach area.

Bolt catcher
energy absorber

Bolt catcher
energy absorber
after bolt impact

Figure 4.2-1-2. Bolt catcher impact testing.

Figure 4.2-1-3. New one-piece forging design.

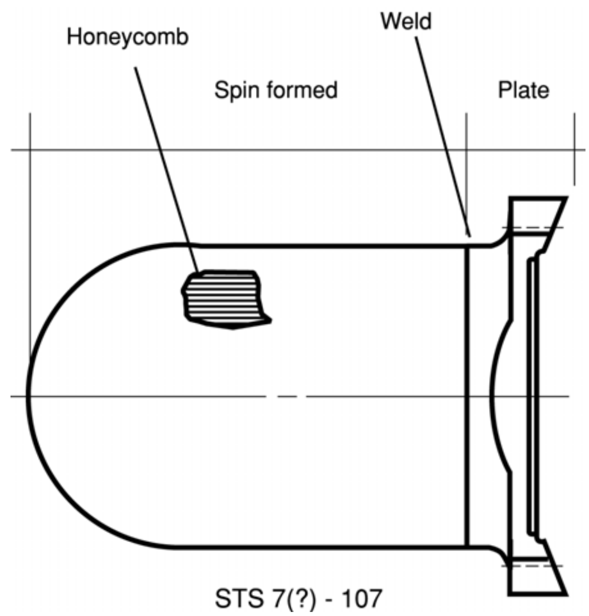


Figure 4.2-1-4. Original two-piece welded design.

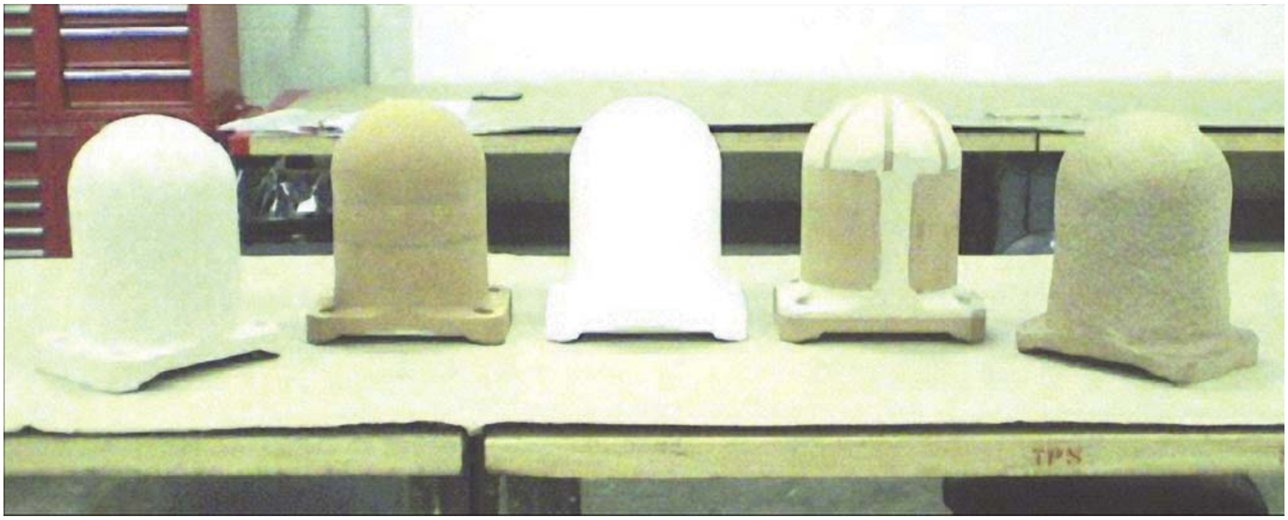


Figure 4.2-1-5. Thermal protection concepts.

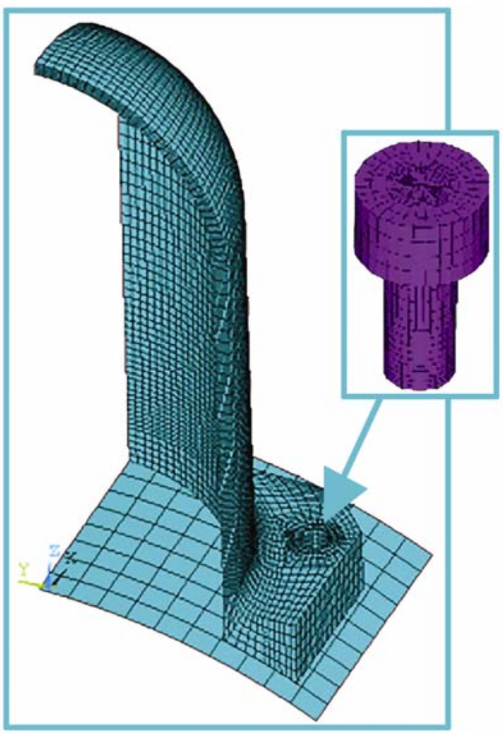


Figure 4.2-1-6. ET bolt/insert finite element model.

STATUS

NASA has completed the redesign of the bolt catcher assembly, the redesign and resizing of the ET attachment bolts and inserts, the testing to characterize the energy absorber material, and the testing to determine the design loads. Structural qualification to demonstrate that the assembly complies with the 1.4 factor-of-safety requirement is under way. Cork has been selected as the Thermal Protection System (TPS) material for the bolt catcher. TPS qualification testing is under way including weather exposure followed by combined environment testing, which includes vibration, acoustic, thermal, and pyrotechnic shock testing.

FORWARD WORK

NASA will complete structural and thermal protection material qualification testing.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	May 04 (Completed)	Complete Critical Design Review
SSP	Sep 04	Complete Qualification
SSP	Oct 04	First Flight Article Available for Delivery

Columbia Accident Investigation Board

Recommendation 4.2-5

Kennedy Space Center Quality Assurance and United Space Alliance must return to the straightforward, industry-standard definition of "Foreign Object Debris," and eliminate any alternate or statistically deceptive definitions like "processing debris." [RTF]

Note: The Stafford Covey Return to Flight Task Group held a plenary session via teleconference on July 22, 2004, in which they reviewed NASA's progress toward answering this recommendation. The Task Group agreed the actions taken were sufficient to conditionally close this recommendation.

BACKGROUND

Beginning in 2001, debris at Kennedy Space Center (KSC) was divided into two categories, "processing debris" and foreign object debris (FOD). FOD was defined as debris found during the final or flight-closeout inspection process. All other debris was labeled processing debris. The categorization and subsequent use of two different definitions of debris led to the perception that processing debris was not a concern.

NASA IMPLEMENTATION

NASA and United Space Alliance (USA) have changed work procedures to consider all debris equally important and preventable. Rigorous definitions of FOD that are the industry standard have been adopted. These new definitions adopted from National Aerospace FOD Prevention, Inc. guidelines and industry standards include Foreign Object Debris (FOD), Foreign Object Damage, and Clean-As-You-Go. FOD is redefined as "a substance, debris or article alien to a vehicle or system which would potentially cause damage."

KSC chartered a multidiscipline NASA/USA team to respond to this recommendation. Team members were selected for their experience in important FOD-related disciplines including processing, quality, and corrective engineering; process analysis and integration; and operations management. The team began by fact-finding and benchmarking to better understand the industry standards and best practices for FOD prevention. They visited the Northrup Grumman facility at Lake Charles, La.; Boeing Aerospace at Kelly Air Force Base, Texas; Gulfstream Aerospace in Savannah, Ga.; and the Air Force's Air Logistics Center in Oklahoma City, Okla. At each site, the team studied the FOD prevention processes, documentation programs, and assurance practices.

Armed with this information, the NASA/USA team developed a more robust FOD prevention program that not only fully answered the *Columbia* Accident Investigation Board (CAIB) recommendation, but also raised the bar by instituting a myriad of additional improvements. The new FOD program is anchored in three fundamental areas of emphasis: First, it eliminates various categories of FOD, including "processing debris," and treats all FOD as preventable and with equal importance. Second, it re-emphasizes the responsibility and authority for FOD prevention at the operations level. Third, it elevates the importance of comprehensive independent monitoring by both contractors and the Government.

USA has also developed and implemented new work practices and strengthened existing practices. This new rigor will reduce the possibility for temporary worksite items or debris to migrate to an out-of-sight or inaccessible area, and it serves an important psychological purpose in eliminating visible breaches in FOD prevention discipline.

FOD "walkdowns" have been a standard industry and KSC procedure for many years. These are dedicated periods during which all employees execute a prescribed search pattern throughout the work areas, picking up all debris. USA has increased the frequency and participation in walkdowns, and has also increased the number of areas that are regularly subject to them. USA has also improved walkdown effectiveness by segmenting FOD walkdown areas into zones. Red zones are all areas within three feet of flight hardware and all areas inside or immediately above or below flight hardware. Yellow zones are all areas within a designated flight hardware operational processing area. Blue zones are desk space and other administrative areas within designated flight hardware operational processing areas.

Additionally, both NASA and USA have increased their independent monitoring of the FOD prevention program. USA Process Assurance Engineers regularly audit work areas for compliance with such work rules as removal of potential FOD items before entering work areas and tethering of those items that cannot be removed (e.g., glasses), tool control protocol, parts protection, and Clean-As-You-Go housekeeping procedures. NASA Quality personnel periodically participate in FOD walkdowns to assess their effectiveness and oversee contractor accomplishment of all FOD program requirements.

An important aspect of the FOD prevention program has been the planning and success of its rollout. USA assigned FOD Point of Contact duties to a senior employee who led the development of the training program from the very beginning of plan construction. This program included a rollout briefing followed by mandatory participation in a new FOD Prevention Program Course, distribution of an FOD awareness booklet, and hands-on training on a new FOD tracking database. Recurrent training will be required once a year and will be enforced by tying work area access renewals to completion of the training. Another important piece of the rollout strategy was the strong support of senior NASA and USA management for the new FOD program and their insistence upon its comprehensive implementation. Managers at all levels will take the FOD courses and will periodically participate in FOD walkdowns.

The new FOD program has a meaningful set of metrics to measure effectiveness and to guide improvements. FOD walkdown findings will be tracked in the Integrated Quality Support Database. This database will also track FOD found during closeouts, launch countdowns, postlaunch pad turnarounds, landing operations, and NASA quality assurance audits. “Stumble-on” FOD findings will also be tracked, as they offer an important metric of program effectiveness independent of planned FOD program activities. For all metrics, the types of FOD and their locations will be recorded and analyzed for trends to identify particular areas for improvement. Monthly metrics reporting to management will highlight the top five FOD types, locations, and observed workforce behaviors, along with the prior months’ trends. Continual improvement will be a hallmark of the revitalized FOD program.

STATUS

NASA and USA have completed the initial benchmarking exercises, identified best practices, modified operating plans and database procedures, and begun the rollout orientation and initial employee training. Official, full-up implementation began on July 1, 2004, although many aspects of the plan existed in the previous FOD prevention program in place at KSC. The full intent of CAIB Recommendation 4.2-5 has been met, and NASA and USA have gone beyond the recommendation to implement a truly world-class FOD prevention program.

FORWARD WORK

Assessment audits by NASA will begin in October 2004 to ensure the ongoing effectiveness of the FOD prevention program. Continual improvement will be vigorously pursued for the remainder of the life of the Shuttle.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
Space Shuttle Program (SSP)	Ongoing	Review and trend metrics
SSP	Oct 03 (Completed)	Initiate NASA Management walkdowns
SSP	Dec 03 (Completed)	FOD Control Program benchmarking
SSP	Jan 04 (Completed)	Revised FOD definition
SSP	Apr 04 (Completed)	Draft USA Operating Procedure released for review
SSP	Jul 04 (Completed)	Implement FOD surveillance
SSP	Oct 04	Baseline audit of implementation of FOD definition, training, and surveillance
SSP	TBD	Periodic surveillance audit

Columbia Accident Investigation Board

Recommendation 6.2-1

Adopt and maintain a Shuttle flight schedule that is consistent with available resources. Although schedule deadlines are an important management tool, those deadlines must be regularly evaluated to ensure that any additional risk incurred to meet the schedule is recognized, understood, and acceptable. [RTF]

BACKGROUND

Schedules are integral parts of program management and provide for the integration and optimization of resource investments across a wide range of connected systems. The Space Shuttle Program (SSP) needs to have a visible schedule with clear milestones to effectively achieve its mission. Schedules associated with all activities generate very specific milestones that must be completed for mission success. Nonetheless, schedules of milestone-driven activities will be extended when necessary to ensure safety. NASA will not compromise system safety in our effort to optimize schedules.

NASA IMPLEMENTATION

NASA's priorities will always be flying safely and accomplishing our missions successfully. NASA will adopt and maintain a Shuttle flight schedule that is consistent with available resources. Schedule risk will be regularly assessed, and unacceptable risk will be mitigated. NASA will develop a process for Shuttle launch schedules that incorporates all of the manifest constraints and allows adequate margin to accommodate a normalized amount of changes. This process will entail building in launch margin, cargo and logistics margin, and crew timeline margin. The SSP will enhance and strengthen the existing risk management system that assesses technical, schedule, and programmatic risks. Additionally, the SSP will examine the risk management process and tools that are currently used by the International Space Station (ISS) where risk data are currently displayed on the One-NASA Management Information System. Senior managers of the Space Operations Mission Directorate can virtually review schedule performance indicators and risk assessments on a real-time basis.

Recent management changes in NASA's key human space flight programs will contribute to ensuring that Shuttle flight schedules are appropriately maintained and amended to be consistent with available resources. In 2002, the Office of Space Operations established the position of Deputy Associate Administrator for International Space Station and Space Shuttle Programs (DAA for ISS/SSP) to manage and direct both programs. This transferred the overall program management of the ISS and SSP from Johnson Space Center to Headquarters (figure 6.2-1-1). The DAA for ISS/SSP was given accountability for the execution of the ISS and SSP, and the authority to establish requirements, direct program milestones, and assign resources, contract awards, and contract fees.

As illustrated in figure 6.2-1-2, the Office of DAA for ISS/SSP employs an integrated resource evaluation process to ensure the effectiveness of both programs. Initial resource allocations are made through our annual budget formulation process. At any given time, there are three fiscal year budgets in work: the current fiscal year budget, the presentation of the next fiscal year Presidential budget to Congress, and preparation of budget guidelines and evaluation of budget proposals for the follow-on year. This overlapping budget process, illustrated in figure 6.2-1-3, provides the means for reviewing and adjusting resources to accomplish an ongoing schedule of activities with acceptable risk.

Defined mission requirements, policy direction, and resource allocations are provided to the ISS and SSP managers for execution. For major decisions affecting return to flight (RTF) efforts, the Space Flight Leadership Council is called upon to provide specific direction. The Office of DAA for ISS/SSP continually evaluates the execution of both programs as policy and mission requirements are implemented with the assigned resources. Resource and milestone concerns are identified through this evaluation process. Continued safe operation of the ISS and SSP is the primary objective of program execution; technical and safety issues are evaluated by the Headquarters DAA staff in preparation for each ISS and SSP mission and continuously as NASA prepares for RTF. As demonstrated in actions before the Columbia accident and continually during the RTF process, adjustments are made to program milestones, such as launch windows, to assure safe and successful operations. Mission anomalies, as well as overall mission performance, are fed back into each program and adjustments are made to benefit future flights.

The Office of DAA for ISS and SSP staff reviews and assesses the status of both programs daily. The cornerstone of the Office of DAA for ISS/SSP staff evaluation process is the NASA Management Information System (MIS) (figure 6.2-1-4). The One-NASA MIS provides NASA senior management with access to critical program data and offers a portal to a significant number of NASA center and program management information systems and Web sites. Among the extensive information on the One-NASA MIS are the Key Program Performance Indicators (KPPIs) (figure 6.2-1-5). The Office of DAA for ISS/SSP uses the KPPIs to present required information to the Space Operations Mission Directorate Program Management Council (PMC) and the Agency PMC on a quarterly basis.

Overall, the Office of DAA for ISS/SSP has implemented a comprehensive process for continually evaluating the effectiveness of the SSP. This process allows the Office of DAA for ISS/SSP staff to recognize and rapidly respond to changes in status, and to act transparently to elevate issues such as schedule changes that may require decisions from the appropriate leaderships. NASA, the Space Flight Leadership Council, and the Office of DAA for ISS/SSP have repeatedly demonstrated an understanding of acceptable risk, and have responded by changing milestones to assure continued safe operation.

STATUS

Currently, all the appropriate manifest owners have initiated work to identify their requirements. SSP now coordinates with the ISS Program to create an RTF integrated schedule.

The SSP Systems Engineering and Integration Office reports the RTF Integrated Schedule every week to the SSP Program Requirements Control Board. Summary briefs are also provided at each Space Flight Leadership Council meeting. SSP Flight Operations has scheduling and manifesting responsibility for the Program, working both the short-term and long-term manifest options. The current proposed manifest launch dates are all "no earlier than" (NET) dates, and are contingent upon the establishment of an RTF date. A computerized manifesting capability, called the Manifesting Assessment System (MAS), is under development to more effectively manage the schedule margin, launch constraints, and manifest flexibility. The primary constraints to launch, including lighting, orbit thermal constraints, and Russian Launch Vehicle constraints, have been incorporated into MAS and tested to ensure proper effects on simulation results. The ability to define and analyze the effects of Orbiter Maintenance Down Period variations and facility utilization are also now part of the system. The system will be improved in the future to include increased flexibility in resource loading enhancements.

FORWARD WORK

The *Columbia* accident has resulted in new requirements that must be factored into the manifest. The ISS and SSP are working together to incorporate the RTF changes into the ISS assembly sequence. A periodic system review of the currently planned flights is being performed. After all the requirements have been analyzed and identified, a launch schedule and ISS manifest is established. NASA will continue to add margin that allows some changes while not causing downstream delays in the manifest.

Development will continue on the computer-aided tools to manage the manifest schedule margin, launch constraints, and manifest flexibility.

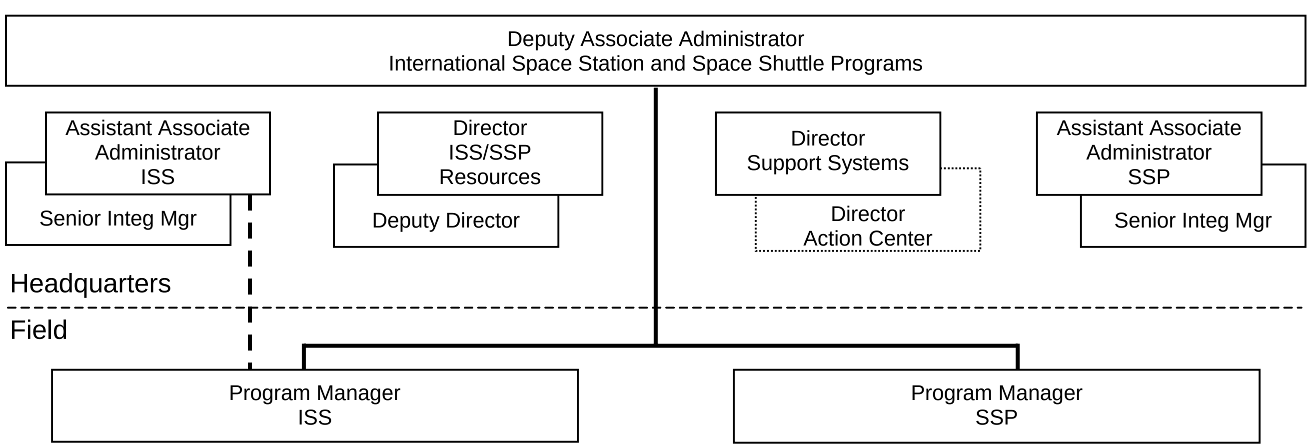


Figure 6.2-1-1. Office of Deputy Associate Administrator for International Space Station and Space Shuttle Programs (Office of Space Operations) is Organized to Maximize Performance Oversight.

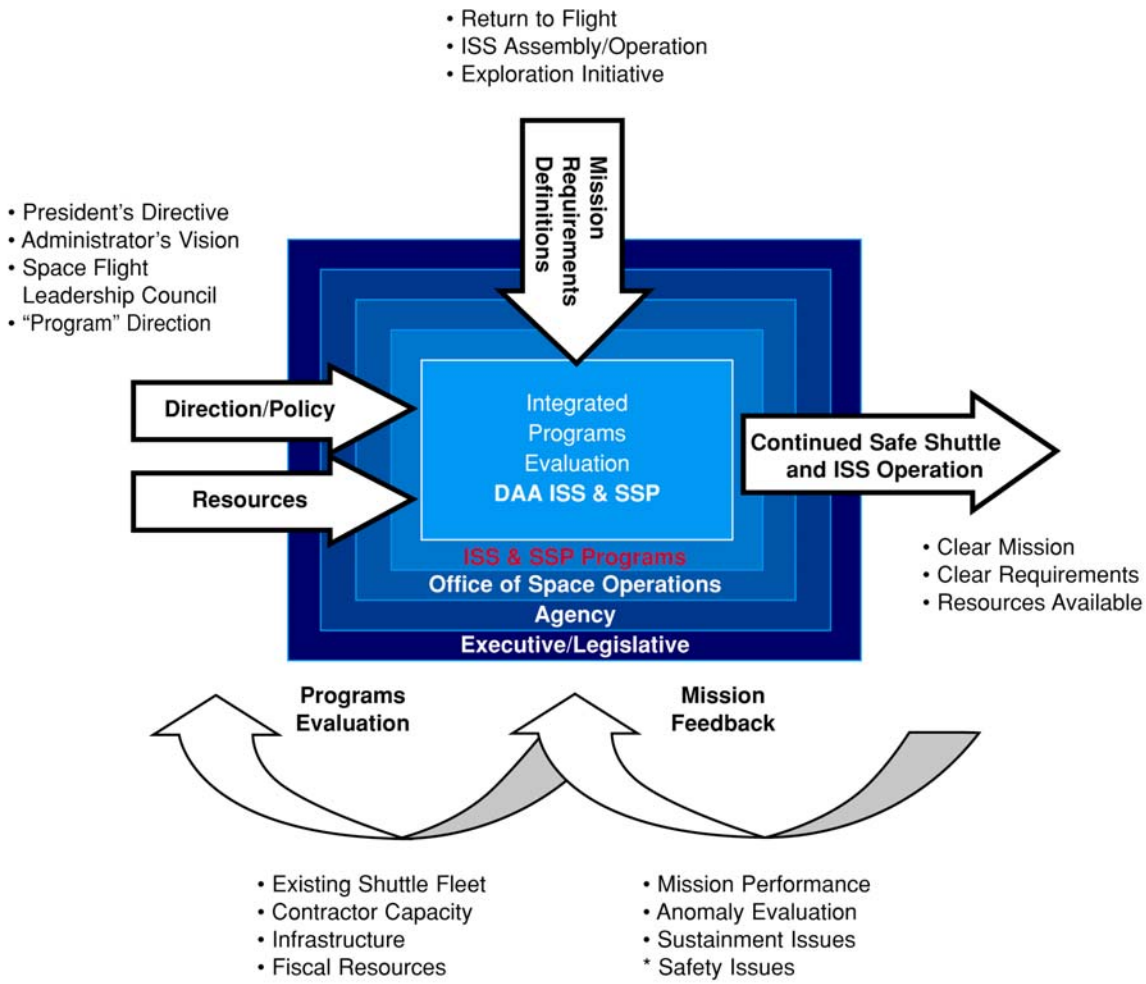


Figure 6.2-1-2. Integrated Resource Evaluation process is Employed by NASA Headquarters, Office of Space Operations.

SSP will be benchmarked against a very effective ISS Program system that currently exists and is well proven for dealing with similar issues.

Until all of the RTF recommendations and implementations plans are identified, a firm STS-114 Shuttle launch schedule cannot be established. In this interim period, the STS-114 launch schedule will be considered an NET schedule and subsequent launch schedules will be based on milestones. The ISS on-orbit configuration is stable and does not drive any particular launch date.

NASA will review our progress on the response to this *Columbia* Accident Investigation Board recommendation with the Stafford-Covey Return to Flight Task Group.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Aug 03 (Completed)	Baseline the RTF constraints schedule
SSP	TBD	Establish STS-114 baseline schedule

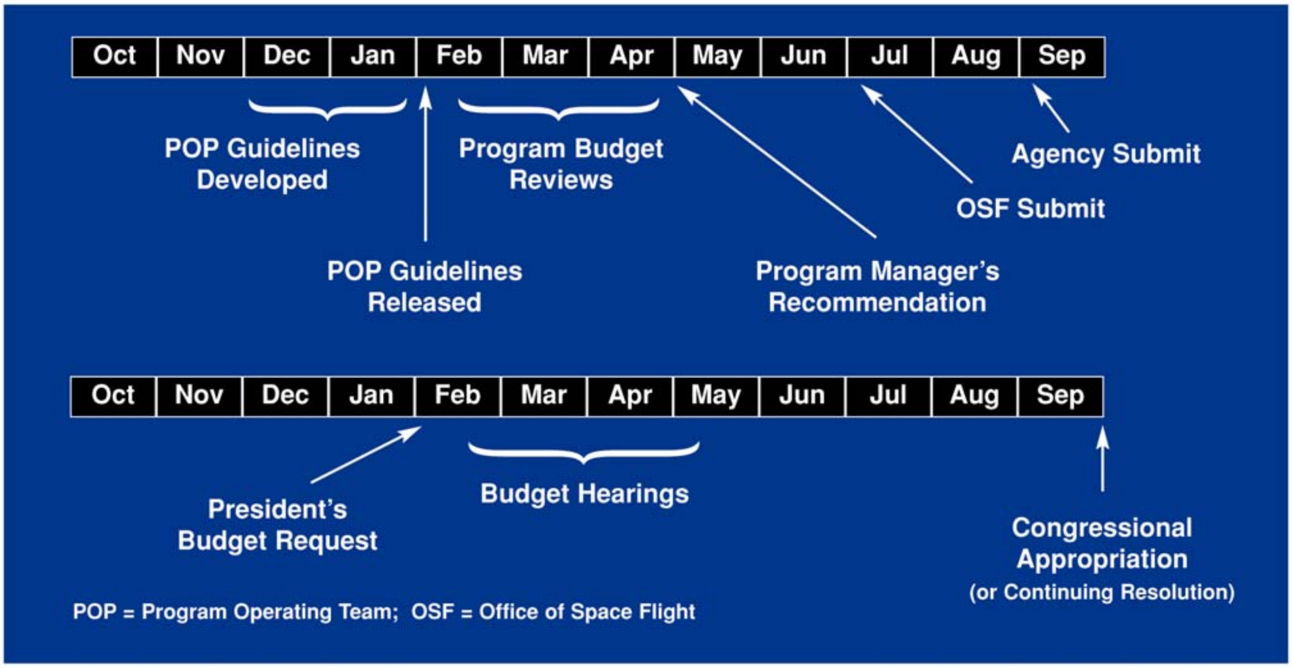


Figure 6.2-1-3. Office of Deputy Associate Administrator for ISS and SSP Annual Budget Formulation Process.

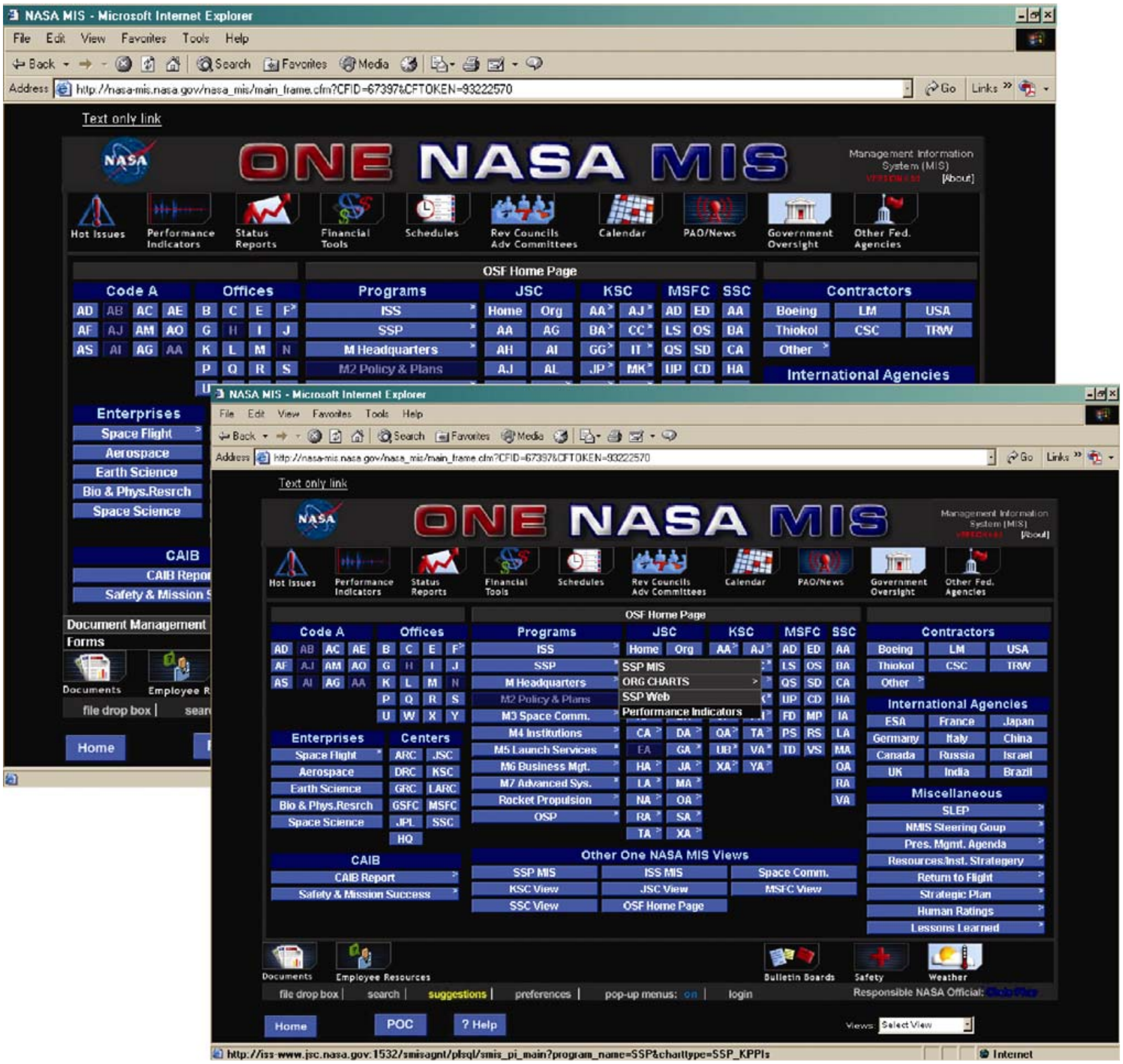


Figure 6.2-1-4. One NASA Management Information System (MIS) is a Tool used to Track Performance of the International Space Station and Space Shuttle Programs.

SHUTTLE
KEY PROGRAM PERFORMANCE INDICATORS (KPPIs)

SSP | SSP KPPIs

Sort --> | Orgs --> | POC --> | Reset

STATUS		PERFORMANCE INDICATOR		RESPONSIBLE ORGANIZATION	ACCOUNTABLE POC
R	SSP KPPI	Cost Summary	DETAILS	MM/Shuttle Business Office	YATES, LUCY
R	SSP KPPI	Development/ Production Summary	DETAILS	MT/Customer and Flight Integration	COGGESHALL, JOHN
Y	SSP KPPI	2020 SLEP	DETAILS	MA/SSP Development	NORBRATEN, LEE
Y	SSP KPPI	Near Term Improvement Integrated Scheudle approved by PRCB	DETAILS	MS/Systems Engineering and Integration	MURATORE, JOHN
Y	SSP KPPI	Processing Overview	DETAILS	KSC/Shuttle Processing	WETMORE, MIKE
Y	SSP KPPI	Program Stoplight Chart	DETAILS	MA/Space Shuttle Program Office	PARSONS, BILL
Y	SSP KPPI	Risk	DETAILS	MA/SSP S&MA	PARSONS, BILL
Y	SSP KPPI	SSP RTF Integrated Schedule and Inchstones	DETAILS	MA/Space Shuttle Program Office	MURATORE, JOHN
Y	SSP KPPI	Shuttle Manifest	DETAILS	MT/Customer and Flight Integration	COGGESHALL, JOHN
Y	SSP	Special Topic: AHMS	DETAILS	MA/SSP Development	NORBRATEN, LEE
G	SSP KPPI	Infrastructure	DETAILS	MK/SSP Launch Integration	WETMORE, MIKE
G	SSP KPPI	SSP Workforce	DETAILS	MM/Shuttle Business Office	YATES, LUCY
G	SSP KPPI	Special Topic: OV-105 OMM	DETAILS	MV/Orbiter	ALLISON, RON

Figure 6.2-1-5. Space Shuttle Key Program Performance Indicators (KPPIs).

Columbia Accident Investigation Board
Recommendation 6.3-1

Implement an expanded training program in which the Mission Management Team faces potential crew and vehicle safety contingencies beyond launch and ascent. These contingences should involve potential loss of Shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations. [RTF]

BACKGROUND

The Mission Management Team (MMT) is responsible for making Space Shuttle Program (SSP) decisions regarding preflight and in-flight activities and operations that exceed the authority of the launch director or the flight director. Responsibilities are transferred from the prelaunch MMT chair to the flight MMT chair once a stable orbit has been achieved. The flight MMT is operated during the subsequent on-orbit flight, entry, landing, and postlanding mission phases through crew egress from the vehicle. When the flight MMT is not in session, all MMT members are on-call and required to support emergency MMTs convened because of anomalies or changing flight conditions.

MMT training, including briefings and simulations, has previously concentrated on the prelaunch and launch phases, including launch aborts.

NASA IMPLEMENTATION

NASA's response will be implemented in two steps: (1) to review and revise MMT processes and procedures; and (2) to develop and implement a training program consistent with those process revisions.

NASA determined through an in-depth review of the processes and functions of STS-107 and previous flight MMTs that additional rigor and discipline are required in the flight MMT process. An essential piece of strengthening the MMT process is ensuring all safety, engineering, and operations concerns are heard and dispositioned appropriately. NASA is expanding the processes for the review and dispositioning of on-orbit anomalies and issues. The flight MMT meeting frequency and the process for requesting an emergency MMT meeting have been more clearly defined. NASA will enforce the requirement to conduct daily MMT meetings.

NASA has established a formal MMT training program comprised of a variety of training activities and MMT simulations. MMT simulations will bring together the flight crew, flight control team, launch control team, engineering staff, outside agencies, and MMT members to improve communication and teach better problem-recognition and reaction skills. All MMT members, except those serving exclusively in an advisory capacity, are required to complete a minimum set of training requirements to attain initial certification prior to performing MMT responsibilities, and participate in a sustained training program to maintain certification. Training records are being maintained to ensure compliance with the new requirements. NASA has employed independent external consultants to assist in developing these training activities and to evaluate overall training effectiveness.

STATUS

The SSP reviewed the MMT processes and revised the Program documentation (NSTS 07700, Volume VIII, Operations, Appendix D) to implement the following significant changes:

1. Membership, organization, and chairmanship of the preflight and in-flight MMT will be standardized. The SSP Deputy Manager will chair both phases of the MMT.

2. Flight MMT meetings will be formalized through the use of standardized agenda formats, presentations, action item assignments, and a readiness poll. Existing SSP meeting support infrastructure will be used to ensure MMT meeting information is distributed as early as possible before scheduled meetings, as well as timely generation and distribution of minutes subsequent to the meetings.

3. Responsibilities for the specific MMT membership have been defined. MMT membership will be expanded and will be augmented with advisory members from the Safety and Mission Assurance (S&MA), Independent Technical Authority, NASA Engineering and Safety Center, and engineering and Program management disciplines. MMT membership for each mission is established by each participating

organization in writing prior to the first preflight MMT.

4. Each MMT member will define internal processes for MMT support and problem reporting.
5. Formal processes will be established for review of findings from ascent and on-orbit imagery analyses, postlaunch hardware inspections, and ascent reconstruction and any other flight data reviews to ensure a timely, positive reporting path for these activities.
6. A process will be established to review and disposition mission anomalies and issues. All anomalies will be identified to the flight MMT. The Space Shuttle Systems Engineering and Integration Office will maintain and provide a status of an integrated anomaly list at each MMT. For those items deemed significant by any MMT member, a formal flight MMT action and office of primary responsibility (OPR) will be assigned and an independent risk assessment will be provided by S&MA. The OPR will provide a status of the action at all subsequent flight MMT meetings. The MMT will require written requests for action closure. The request must include a description of the issue (observation and potential consequences), analysis details (including employed models and methodologies), recommended actions and associated mission impacts, and flight closure rationale, if applicable.

NASA has also completed a Mission Evaluation Room console handbook that includes MMT reporting requirements, a flight MMT reporting process for on-orbit vehicle inspection findings, and MMT meeting support procedures. Additionally, the SSP published a formal MMT training plan (NSTS 07700, Volume II, Program Structure and Responsibilities, Book 2 - Space Shuttle Program Directives, Space Shuttle Program Directive 150) that defines the generic training requirements for MMT certification. This plan is comprised of three basic types of training: courses and workshops, MMT simulations, and self-instruction. Courses, workshops, and self-instruction materials were selected to strengthen individual expertise in human factors, critical decision making, and risk management of high-reliability systems. Additionally, the SSP published a fiscal year (FY) 2004 training calendar that identifies the specific training activities to be conducted in FY 2004 and, for each activity, the associated date, objective, location, and point of contact. MMT training activities are well under way with several courses/workshops held at various NASA centers and seven simulations completed.

FORWARD WORK

Revisions to project and element processes will be established consistent with the new MMT requirements and will follow formal Program approval. Associated project and element activities in development include but are not limited to a flight MMT reporting process for launch imagery analysis and on-orbit vehicle inspection findings.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Oct 03 (Completed)	MMT Interim training plan
SSP	Oct 03 (Completed)	MMT process changes to Program Requirements Change Board
SSP	Oct 03 (Completed)	Project/element process changes
SSP	Nov 03 – Return to Flight	MMT training
SSP		MMT Simulation Summary
	Nov 03 (Completed)	MMT On-Orbit simulation
	Dec 03 (Completed)	MMT SSP/International Space Station (ISS) Joint On-Orbit simulation
	Feb 04 (Completed)	MMT On-Orbit simulation
	Apr 04 (Completed)	MMT Prelaunch simulation
	May 04 (Completed)	MMT On-Orbit simulation involving Thermal Protection System (TPS) inspection
	Jun 04 (Completed)	MMT Prelaunch simulation
	Jul 04 (Completed)	MMT On-Orbit simulation
	Sep 04	MMT Prelaunch simulation
	Sep 04	MMT On-Orbit simulation
	Oct 04	MMT Prelaunch Contingency simulation
	Nov 04	MMT SSP/ISS Joint On-Orbit simulation involving TPS inspection and national assets
	Jan 05	MMT Prelaunch/On-Orbit/Entry Integrated simulation
SSP	Dec 03 (Completed)	Status to Space Flight Leadership Council and Stafford/Covey Task Group
SSP	Feb 04 (Completed)	MMT final training plan
SSP	Apr 04 (Completed)	Status to Stafford/Covey Task Group
SSP	Aug 04 (Completed)	Miscellaneous MMT process revisions to address simulations lessons learned
SSP	Sep 04	Status to Stafford/Covey Return to Flight Task Group
SSP	Dec 04	Closure to Stafford/Covey Return to Flight Task Group

Columbia Accident Investigation Board

Recommendation 10.3-1

Develop an interim program of closeout photographs for all critical sub-systems that differ from engineering drawings. Digitize the closeout photograph system so that images are immediately available for on-orbit troubleshooting. [RTF]

Note: The Stafford Covey Return to Flight Task Group held a plenary session on July 22, 2004, and NASA's progress toward answering this recommendation was reviewed. The Task Group agreed the actions taken were sufficient to conditionally close this recommendation.

BACKGROUND

Closeout photography is used, in part, to document differences between actual hardware configuration and the engineering drawing system. The *Columbia* Accident Investigation Board (CAIB) recognized the complexity of the Shuttle drawing system and the inherent potential for error and recommended to upgrade the system (ref. CAIB Recommendation 10.3-2).

Some knowledge of vehicle configuration can be gained by reviewing photographs maintained in the Kennedy Space Center (KSC) Quality Data Center film database or the digital Still Image Management System (SIMS) database. NASA now uses primarily digital photography. Photographs are taken for various reasons, such as to document major modifications, visual discrepancies in flight hardware or flight configuration, and vehicle areas that are closed for flight. NASA employees and support contractors can access SIMS. Prior to SIMS, images were difficult to locate, since they were typically retrieved by cross-referencing the work-authorizing document that specifies them.

NASA IMPLEMENTATION

NASA formed a Photo Closeout Team consisting of members from the engineering, quality, and technical communities to identify and implement necessary upgrades to the processes and equipment involved in vehicle closeout photography. KSC closeout photography includes the Orbiter, Space Shuttle Main Engine, Solid Rocket Boosters, and External Tank based on Element Project requirements. The Photo Closeout Team divided the CAIB action into two main elements: (1) increasing the quantity and quality of closeout photographs, and (2) improving the retrieval process through a user-friendly Web-based graphical interface system (figure 10.3-1-1).

Increasing the Quantity and Quality of Photographs

Led by the Photo Closeout Team, the Space Shuttle Program (SSP) completed an extensive review of existing closeout photo requirements. This multi-center, multi-element, NASA and contractor team systematically identified the deficiencies of the current system and assembled and prioritized improvements for all Program elements. These priorities were distilled into a set of revised requirements that has been incorporated into Program documentation. Newly identified requirements included improved closeout photography of extravehicular activity tool contingency configurations and middeck and payload bay configurations. NASA has also added a formal photography work step for KSC-generated documentation and mandated that photography of all Material Review Board (MRB) reports be archived in the SIMS. These MRB problem reports provide the formal documentation of known subsystem and component discrepancies, such as differences from engineering drawings.

To meet the new requirements and ensure a comprehensive and accurate database of photos, NASA established a baseline for photo equipment and quality standards, initiated a training and certification program to ensure that all operators understand and can meet these requirements, and improved the SIMS. To verify the quality of the photos being taken and archived, NASA has developed an ongoing process that calls for SIMS administrators to continually audit the photos being submitted for archiving in the SIMS. Operators who fail to meet the photo requirements will be decertified pending further training. Additionally, to ensure the robustness of the archive, poor-quality photos will not be archived.

NASA determined that the minimum resolution for closeout photography should be 6.1 megapixels to provide the necessary clarity and detail. KSC has procured 36 Nikon 6.1 megapixel cameras and completed a test program in cooperation with Nikon to ensure that the cameras meet NASA's requirements.

Improving the Photograph Retrieval Process

To improve the accessibility of this rich database of Shuttle closeout images, NASA has enhanced SIMS by developing a Web-based graphical interface. Users will be able to easily view the desired Shuttle elements and systems and quickly drill down to specific components, as well as select photos from specific Orbiters and missions. SIMS will also include hardware reference drawings to help users identify hardware locations by zones. These enhancements will enable the Mission Evaluation Room (MER) and Mission Management Team to quickly and intuitively access relevant photos without lengthy searches, improving their ability to respond to contingencies.

To support these equipment and database improvements, NASA and United Space Alliance (USA) have developed a training program for all operators to ensure consistent photo quality and to provide formal certification for all camera operators. Additional training programs have also been established to train and certify Quality Control Inspectors and Systems Engineering personnel; to train Johnson Space Center (JSC) SIMS end users, such as staff in the MER; and to provide a general SIMS familiarization course. An independent Web-based SIMS familiarization training course is also in development.

STATUS

NASA has revised the Operation and Maintenance Requirements System (OMRS) to mandate that general closeout photography be performed at the time of the normal closeout inspection process and that digital photographs be archived in SIMS. Overlapping photographs will be taken to capture large areas. NSTS 07700 Volume IV and the KSC MRB Operating Procedure have also been updated to mandate that photography of visible MRB conditions be entered into the SIMS closeout photography database. This requirement ensures that all known critical subsystem configurations that differ from Engineering Drawings are documented and available in SIMS to aid in engineering evaluation and on-orbit troubleshooting.

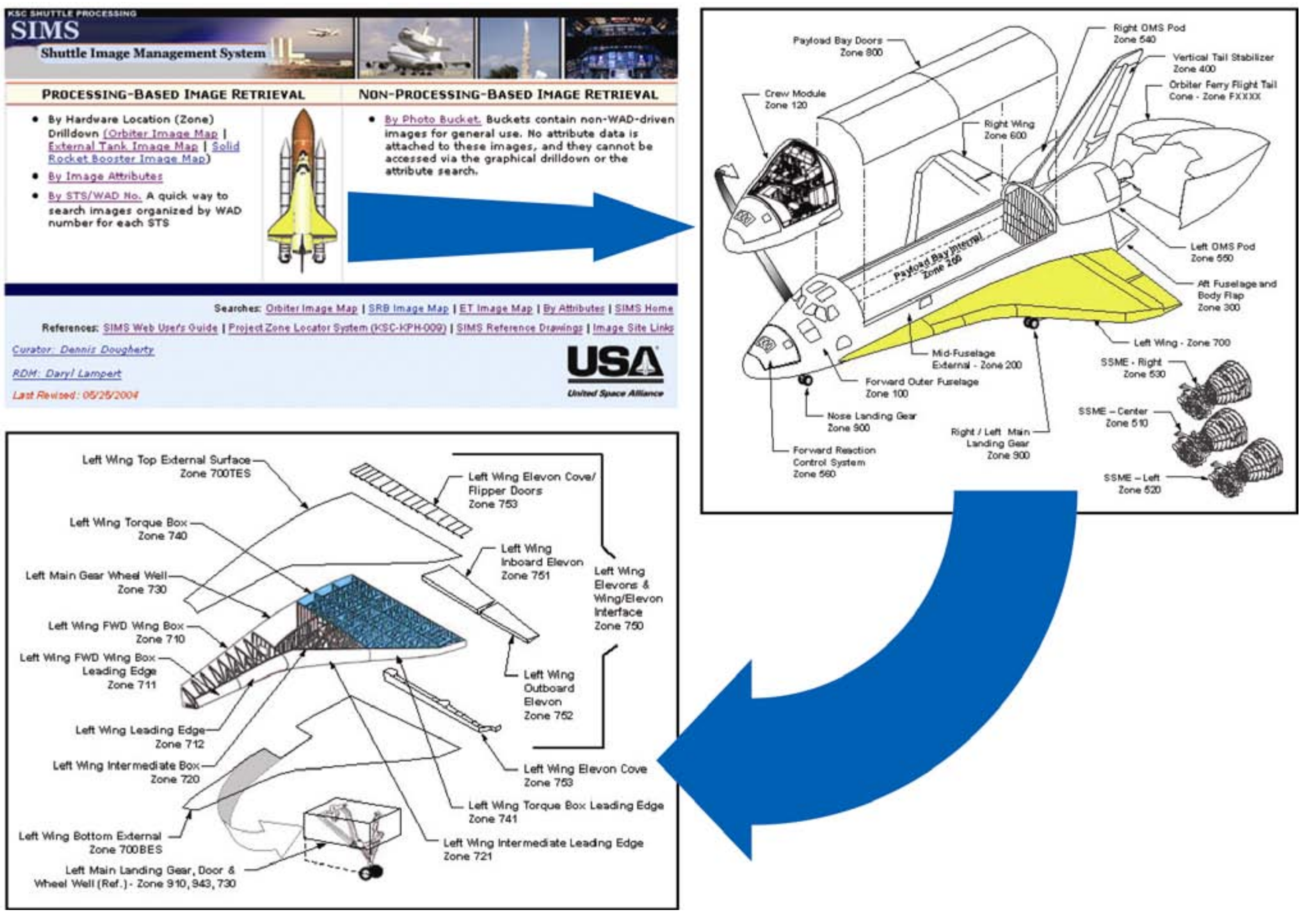


Figure 10.3-1-1. Enhanced SIMS graphic interface.

The revised Shuttle Program closeout photography requirements are documented in RCN KS16347R1 to OMRS File II, Volume I S00GEN.625 and S00GEN.620. Additionally, NASA Quality Planning Requirements Document (QPRD) SFOC-GO0007 Revision L and USA Operation Procedure USA 004644, "Inspection Points and Personnel Traceability Codes," were updated to be consistent with the revised OMRS and QPRD documents.

The upgraded SIMS is operational and available for use by all SSP elements. Training for critical personnel is complete, and will be ongoing to ensure the broadest possible dissemination within the user community.

FORWARD WORK

Training is under way for the photographers at KSC who will use the new equipment; training is expected to be complete by October 1, 2004.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Feb 04 (Completed)	Develop SIMS drilldown and graphical requirements
SSP	Apr 04 (Completed)	Projects transmit photo requirements to KSC Ground Operations
KSC	May 04 (Completed)	Complete graphical drilldown software implementation
KSC	Jun 04 (Completed)	Develop/complete SIMS training module
KSC	Jul 04 (Completed)	Provide training to MER. Demonstrate SIMS interface to JSC/Marshall Space Flight Center
KSC	Oct 04	Photographer Training

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 2

The Space Shuttle Program will evaluate relative risk to all persons and property underlying the entry flight path. This study will encompass all landing opportunities from each inclination to each of the three primary landing sites.

BACKGROUND

The *Columbia* accident highlighted the need for NASA to better understand entry overflight risk. In its report, the *Columbia* Accident Investigation Board (CAIB) observed that NASA should take steps to mitigate the risk to the public from Orbiter entries. Before returning to flight, NASA is dedicated to understanding and diminishing potential risks associated with entry overflight, a topic that is also covered in CAIB Observations 10.1-2 and 10.1-3.

NASA IMPLEMENTATION

All of the work being done to improve the safety of the Space Shuttle also reduces the risk to the public posed by any potential vehicle failures during ascent or entry. These technical improvements will be paired with operational changes to further reduce public risk. These operational changes include improved insight into the Orbiter's health prior to entry; new flight rules and procedures to manage entry risk; and landing site selection that factors in public risk determinations as appropriate.

The overflight risk from impacting debris is a function of three fundamental factors: (1) the probability of vehicle loss of control (LOC) and subsequent breakup, (2) surviving debris, and (3) the population living under the entry flight path. NASA has identified the phases of entry that present a greater probability of LOC based on elements such as increased load factors, aerodynamic pressures, and thermal conditions. Other factors, such as the effect of population sheltering, are also considered in the assessment. The measures undertaken to improve crew safety and vehicle health will result in a lower probability of LOC, thereby improving the public safety during entry overflight.

NASA is currently studying the relative public risks associated with entry to its three primary landing sites: Kennedy Space Center (KSC) in Florida; Edwards Air Force Base (EDW) in California; and White Sands Space Harbor/Northrup (NOR) in New Mexico. We have evaluated the full range of potential ground tracks for each site and conducted sensitivity studies to assess the overflight risk for each. NASA is incorporating population overflight, as well as crew considerations, into the entry flight rules that guide the flight control team's selection of landing opportunities.

STATUS

For NASA's preliminary relative risk assessment of the Shuttle landing tracks, more than 1200 entry trajectories were simulated for all three primary landing sites from all of the previously used Shuttle orbit inclinations: 28.5° (Hubble Space Telescope), 39.0° (STS-107), and 51.6° (International Space Station). The full range of entry crossrange[1] possibilities to each site was studied in increments of 25 nautical miles for all ascending (south to north) and descending (north to south) approaches. Figure SSP 2-1 displays the ground tracks simulated for the 51.6° inclination orbit. Although these preliminary results indicate that some landing opportunities have an increased public risk compared to others, the uncertainty of the input factors must be further reduced in order to make reliable decisions regarding public risk.

The Space Shuttle Program (SSP) has recommended that the current landing site priorities be maintained, and that KSC remain our primary landing site. NASA will use operational methods and vehicle safety improvements implemented in preparation for return to flight (RTF) to minimize the risk to the public posed by LOC during overflight.

NASA Headquarters (HQ) released a draft policy on ensuring public safety during all phases of space flight missions. The policy is currently under review by all stakeholders.

[1] Entry crossrange is defined as the distance between the landing site and the point of closest approach on the orbit ground track. This number is operationally useful to determine whether or not the landing site is within the Shuttle's entry flight capability for a particular orbit.

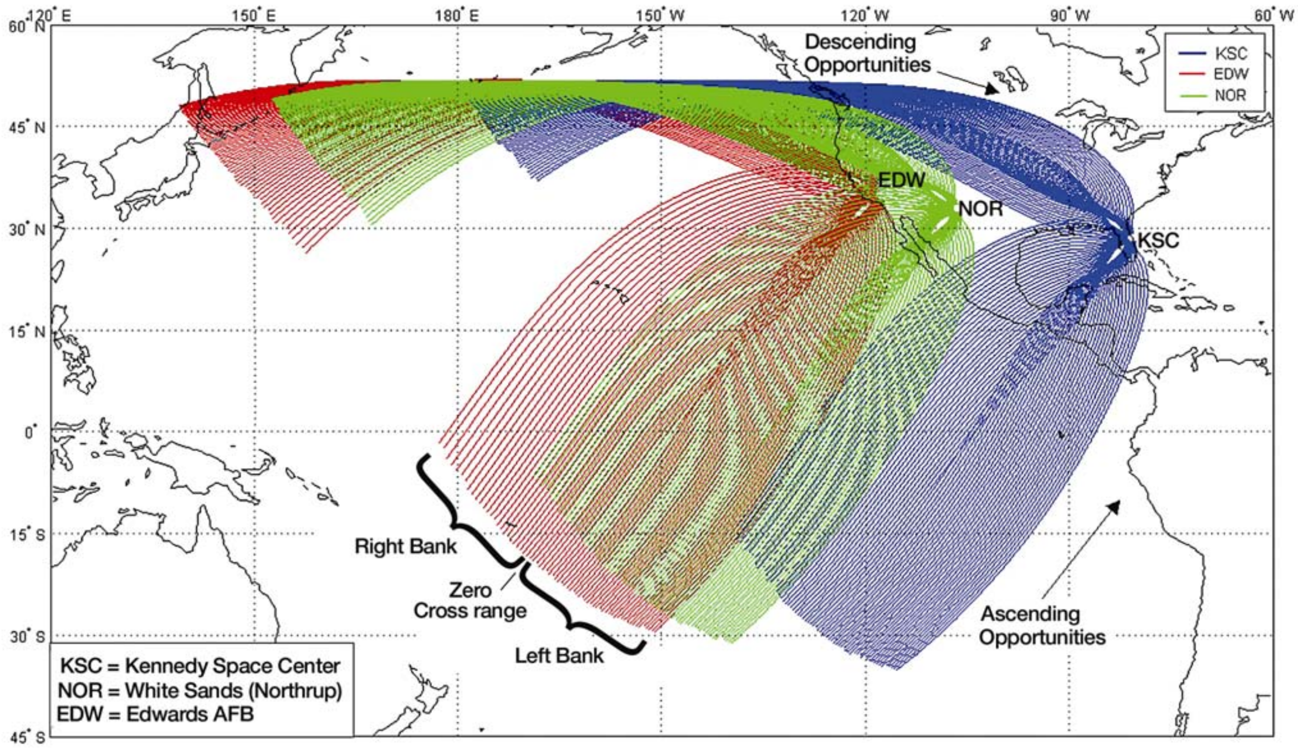


Figure SSP 2-1. Possible entry ground tracks from 51.6° orbit inclination. Blue lines are landing at KSC, green at NOR, red at EDW.

FORWARD WORK

The Johnson Space Center, the Chief Safety and Mission Assurance officer at NASA HQ, and the Agency Range Safety Program will coordinate activities and share all analyses, research, and data obtained as part of this RTF effort. This shared work is being applied to the development of an Agency Range Safety Policy addressing public risk for all phases of space flight missions.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Preliminary results to RTF Planning Team and SSP Program Requirements Control Board (PRCB)
SSP	Sep 03 (Completed)	Update to RTF Planning Team and SSP PRCB
SSP	Jan 04 (Completed)	Update to RTF Planning Team and SSP PRCB
SSP	Jun 04 (Completed)	Update to SSP PRCB
SSP	Jun 04 (Completed)	Entry risk overview to NASA HQ
SSP	Sep 04	Update to SSP PRCB
SSP	Oct 04	Report to SSP PRCB
NASA HQ	Nov 04	Agency Range Safety policy approval

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 5

NASA will determine critical debris sources, transport mechanisms, and resulting impact areas. Based on the results of this assessment, we will recommend changes or redesigns that would reduce the debris risk. NASA will also review all Program baseline debris requirements to ensure appropriateness and consistency.

BACKGROUND

A review of critical debris potential is necessary to prevent the recurrence of an STS-107 type of failure. NASA is improving the end-to-end process of predicting debris impacts and the resulting damage.

NASA IMPLEMENTATION

NASA will analyze credible debris sources from a wide range of release locations to predict the impact location and conditions. It will develop critical debris source zones to provide maximum allowable debris sizes for various locations on the vehicle. Debris sources that can cause significant damage may be redesigned. Critical impact locations may also be redesigned or debris protection added.

A list of credible ascent debris sources has been compiled for each Shuttle Program hardware element—Solid Rocket Booster, Reusable Solid Rocket Motor, Space Shuttle Main Engine, External Tank, Orbiter, and the pad area around the vehicle at launch. Potential debris sources have been identified by their location, size, shape, material properties, and, if applicable, likely time of debris release. This information will be used to conduct a debris transport analysis to predict impact location and conditions, such as velocities and relative impact angles.

NASA will analyze over two hundred million debris transport cases. These will include debris type, location, size, and release conditions (freestream Mach number, initial velocity of debris piece, etc.).

STATUS

All hardware project and element teams have identified known and suspected debris sources originating from the flight hardware. The debris source tables for all of the propulsive elements mentioned above have been formally reviewed and approved. The debris source tables for the remaining two flight elements, the External Tank and the Orbiter, are in the final steps of review before being baselined. The pad environment table was added after work had commenced on the flight elements, and will require additional time to complete.

The debris transport tools have been completely rewritten and the results have been peer reviewed. NASA has completed the transport analysis for the initial 16 debris cases; the resulting data has been provided to the Space Shuttle Program (SSP) elements for evaluation. Preliminary damage tolerance assessments are in work, and the initial set of allowable debris limits for ET foam has been established and is being baselined. A second set of debris transport cases is being initiated in August 2004, with an updated methodology that reduces assumptions and unknowns in the first round.

NASA has also completed a supersonic wind tunnel test at the NASA Ames Research Center. This test validated the debris transport flow fields in the critical Mach number range. Preliminary results show excellent agreement between wind tunnel results and analytically derived flow field predictions.

Interim results of these analyses have already helped the Shuttle Program to respond to the *Columbia* Accident Investigation Board recommendations such as those on External Tank modifications (R3.2-1), Orbiter hardening modification (R3.3-2), and ascent and on-orbit imagery requirements (R3.4-1 and R3.4-3).

FORWARD WORK

NASA will continue to update its transport analyses as SSP elements increase the fidelity of debris shedding material characteristics. As a part of this process, applicable mass and density ranges will be refined.

The results of the second set of debris transport analyses will be provided to all SSP elements for their analysis of debris impact capability.

SCHEDULE

This is an extensive action that will take a year or more to fully complete. The preliminary schedule, included below, is dependent on use of current damage assessment tools. If additional testing and tool development are required, it may increase the total time required to complete the action.

Responsibility	Due Date	Activity/Deliverable
SSP	Jul 03 (Completed)	Elements provide debris history/sources
SSP	Nov 03 (Completed)	Begin Return to Flight (RTF) Debris Transport analyses
SSP	Aug 04	Begin next set of Debris Transport analyses (approximately 30–40 cases)
SSP	Sep 04	Summary Report/Recommendation to Program Requirements Control Board (PRCB)-RTF cases only
SSP	Nov 04	Summary report/recommendation to PRCB

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 6

All waivers, deviations, and exceptions to Space Shuttle Program (SSP) requirements documentation will be reviewed for validity and acceptability before return to flight.

BACKGROUND

Requirements are the fundamental mechanism by which the Space Shuttle Program (SSP) directs the production of hardware, software, and training for ground and flight personnel to meet performance needs. The rationale for waivers, deviations, and exceptions to these requirements must include compelling proof that the associated risks are mitigated through design, redundancy, processing precautions, and operational safeguards. The Program manager has approval authority for waivers, deviations, and exceptions. However, final approval authority resides with the Independent Technical Authority (ITA).

NASA IMPLEMENTATION

Because waivers and deviations to SSP requirements and exceptions to the Operations and Maintenance Requirements and Specifications contain the potential for unintended risk, the Program has directed all elements to review these exemptions to Program requirements to determine whether the exemptions should be retained. The ITA will have final authority over which waivers, deviations, and exemptions are acceptable.

Each project and element will be alert for items that require mitigation before return to flight. The projects and elements will also identify improvements that should be accomplished as part of the Space Shuttle Service Life Extension Program.

The following instructions were provided to each project and element:

1. Any item that has demonstrated periodic, recurrent, or increasingly severe deviation from the original design intention must be technically evaluated and justified. If there is clear engineering rationale for multiple waivers for a Program requirement, it could mean that a revision to the requirement is needed. The potential expansion of documented requirements should be identified for Program consideration.
2. The review should include the engineering basis for each waiver, deviation, or exception to ensure that the technical rationale for acceptance is complete, thorough, and well considered.
3. Each waiver, deviation, or exception should have a complete engineering review to ensure that incremental risk increase has not crept into the process over the Shuttle lifetime and that the level of risk is appropriate.

The projects and elements were encouraged to retire out-of-date waivers, deviations, and exceptions.

In addition to reviewing all SSP waivers, deviations, and exceptions, each element is reviewing all NASA Accident Investigation Team working group observations and findings and Critical Item List (CIL) waivers associated with ascent debris.

STATUS

Each project and element presented a plan and schedule for completion to the daily Program Requirements Control Board (PRCB) on June 25, 2003. Each project and element is identifying and reviewing the CIL waivers associated with ascent debris generation.

FORWARD WORK

The SSP continues to review the waivers, deviations, and exceptions at the daily PRCB. These items will be coordinated with the ITA as appropriate.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SSP	Nov 04	Review of all waivers, deviations, and exceptions

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 7

The Space Shuttle Program (SSP) should consider NASA Accident Investigation Team (NAIT) working group findings, observations, and recommendations.

BACKGROUND

As part of their support of the *Columbia* Accident Investigation Board (CAIB), each NASA Accident Investigation Team (NAIT) technical working group compiled assessments and critiques of Program functions. These assessments offer a valuable internal review and will be considered by the Space Shuttle Program (SSP) for conversion into directives for corrective actions.

NASA IMPLEMENTATION

All NAIT technical working groups have an action to present their findings, observations, and recommendations to the Space Shuttle Program Requirements Control Board (PRCB). Each project and element will disposition recommendations within its project to determine which should be return to flight actions. Actions that require SSP or Agency implementation will be forwarded to the PRCB for disposition.

STATUS

The following NAIT working groups have reported their findings and recommendations to the SSP at the PRCB: the Space Shuttle Main Engine Project Office, the Reusable Solid Rocket Motor Project Office, the Mishap Investigation Team, the External Tank Project, the Solid Rocket Booster Project Office, and Space Shuttle Systems Integration. The Orbiter Project Office has reported the findings and recommendations of the following working groups to the PRCB: *Columbia* Early Sighting Assessment Team, Certification of Flight Readiness Process Team, Unexplained Anomaly Closure Team, Previous Debris Assessment Team, Hardware Forensics Team, Materials Processes and Failure Analysis Team, Starfire Team, Integrated Entry Environment Team, Image Analysis Team, Palmdale Orbiter Maintenance Down Period Team, Space/Atmospheric Scientist Panel, KSC Processing Team, *Columbia* Accident Investigation Fault Tree Team, *Columbia* Reconstruction Team, and Hazard Controls Analysis Team.

Project and PRCB recommendations currently being implemented include revision of the SSP Contingency Action Plan, modifications to the External Tank, and evaluation of hardware qualification and certification concerns. Numerous changes to Orbiter engineering, vehicle maintenance and inspection processes, and analytical models are also being made as a result of the recommendations of the various accident investigation working groups. In addition, extensive changes are being made to the integrated effort to gather, review, and disposition prelaunch, ascent, on-orbit, and entry imagery of the vehicle, and to evaluate and repair any potential vehicle damage observed. All of this work complements and builds upon the extensive recommendations, findings, and observations contained in the CAIB Report.

FORWARD WORK

Recommendations from the Space Shuttle Systems Engineering and Integration Office are scheduled for review by the PRCB in September 2004.

SCHEDULE

Following PRCB approval of recommendations, the responsible project office will develop implementation schedules, with the goal of implementing approved recommendations prior to return to flight.

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 14

Determine critical Orbiter impact locations and TPS damage size criteria that will require on-orbit inspection and repair. Determine minimum criteria for which repairs are necessary and maximum criteria for which repair is possible.

BACKGROUND

The Space Shuttle Thermal Protection System (TPS) consists of various materials applied externally to the outer structural skin of the Orbiter. These materials allow the skin temperatures to remain within acceptable limits during the extreme temperatures encountered during entry. As in the case of the *Columbia* accident, failure of the TPS can result in the catastrophic loss of the crew and vehicle. The TPS is composed of an assortment of materials that includes Reinforced Carbon-Carbon (RCC), ceramic tiles, Nomex-coated blankets, thermal panes, metals, silica cloths, and vulcanizing material.

Failure of the TPS can be caused by debris impact. The debris impact location, energy, impact angle, material, density, and shape are all critical factors in determining the effects of the debris impact on the TPS.

NASA IMPLEMENTATION

NASA is developing models to accurately predict the damage resulting from a debris impact, and a damage-tolerance test plan is in work. NASA is also developing more mature models to determine if damage is survivable or must be repaired before safe entry.

The Space Shuttle Program Requirements Control Board (PRCB) issued an action that encompasses all efforts related to the testing and analysis necessary to determine the thresholds between damage and no-damage cases, and between damage that is safe for entry versus damage that must be repaired. This action also addresses the development of models to improve tile and RCC damage prediction, and to determine the maximum possible repair capability while in flight. To fulfill this PRCB action, the Orbiter Debris Impact Assessment Team (ODIAT) was created to integrate all NASA, United Space Alliance, Boeing, and Lockheed-Martin efforts necessary to determine the different debris damage thresholds for both tile and RCC and to develop predictive debris damage models. Figure SSP 14-1 shows the interfaces between the ODIAT and various new or existing teams that are working return to flight (RTF) activities.

The ODIAT effort is comprised of four main activities:

- Impact testing on tile, RCC flat plates, and full RCC panels;
- Material property testing of RCC coupons and potential debris types;
- Analysis and integration of test results into predictive models; and
- Damage tolerance testing and analysis to determine the threshold for damage that must be repaired.

STATUS

Efforts are under way for each of the major focus areas. Foam impact tile testing is ongoing at Southwest Research Institute (SwRI) in San Antonio, Texas. The only tests remaining to be completed are the tests on “special configuration” tiles (such as those around doors and windows) and some lower mass projectile impact tests on acreage tiles. High-density ice impact tests at the White Sands Test Facility and ablator impact tests at Kennedy Space Center are under way and are targeted for completion by the end of August 2004. The first test used a 0.1-lb. foam projectile at a velocity of 701 ft/sec; no damage resulted from the impact. A second foam impact of 0.2 lb. at 688 ft/sec also produced no damage. The final test used a 0.167-lb. piece of foam shot at 1167 ft/sec, and caused severe cracking of the panel, but did not actually create a hole in the panel. Another series of impact tests on a full scale panel (16R) will be performed in September 2004.

Coupon testing for RCC material properties is under way at Southern Research Institute in Birmingham, Alabama. Data from testing thus far indicate that flown material (panel 8L from OV-104 with 26 flights) has material properties slightly degraded from new material, but significantly higher than the allowables used in the mission life models for RCC. Data from these tests are being used to verify and modify new models. The production of additional RCC coupon material for testing has been completed at Lockheed-Martin in Dallas. These panels are undergoing foam impact tests at the Glenn Research Center (GRC). Ice impact testing against these panels will follow.

Analysis and modeling work is continuing for both the RCC and the tile. The data collected will be used to develop and verify two types of RCC and tile models. One model will be used in real-time situations where a timely answer is needed. This model will provide a conservative answer to possible damage assessments. The second model will provide very accurate predictions of possible damage. This model may take several days to code and run and will be used for situations where time is available and detailed results are necessary. The analysis and modeling tasks are being worked in conjunction with Boeing, Langley Research Center, GRC, and SwRI. The detailed RCC model has shown very good correlation to actual testing with foam projectiles, and developmental work on the other models is continuing.

Damage tolerance testing is under way at Langley Research Center and Johnson Space Center. Through structural and thermal testing of damaged RCC and tile samples, we can determine exactly how much damage can be allowed while still ensuring a safe return for the crew and vehicle. Testing thus far has shown that RCC cannot tolerate a loss of coating from both the front surface in areas that experience full heating/temperatures. This is because the impacts can create subsurface delamination of the RCC. Testing has indicated that any loss of front-side coating in areas that are hot enough to oxidize and/or promote full heating of the damaged substrate will cause unacceptable erosion damage.

FORWARD WORK

NASA will continue to conduct tests that provide insights into the material and physical properties of the TPS. NASA is also developing damage criteria for the TPS by performing impact tests and arc jet tests. Results from these tests will also help to determine the location dependencies of the impacting debris. Techniques for repairing tile and RCC are under development. The ability of the International Space Station crew to provide support to an Orbiter crew during a Shuttle TPS repair scenario or during a crew rescue operation is under investigation. The combination of these capabilities will help to ensure a lower probability that critical damage will be sustained, while increasing the probability that any damage that does occur can be detected and the consequences mitigated during flight.

Additional information related to this action can be found in other sections of this Implementation Plan. Information on the damage that the TPS can sustain, and still allow for successful entry of the Orbiter into Earth's atmosphere, is further explained in NASA's response to Recommendation R3.3-3. Information regarding the TPS inspection and repair capabilities being investigated is further explained in NASA's answer to Recommendations R6.4-1 and R3.3-2.

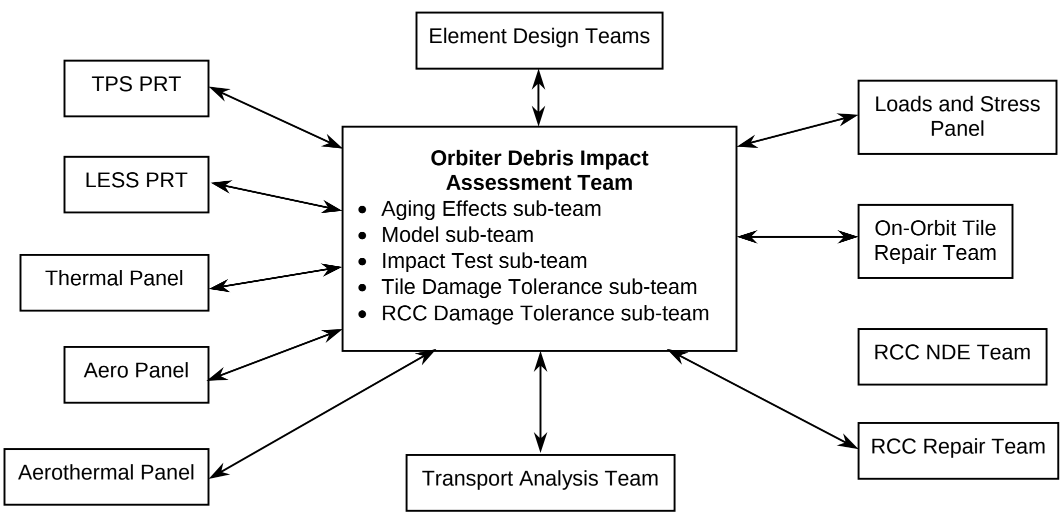


Figure SSP 14-1. Orbiter Debris Impact Assessment Team integrates efforts from other teams.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
ODIAT	Oct 03 (Completed)	Panel 9 Testing
ODIAT	Sep 04	Panel 16R Testing
ODIAT	Sep 04	RCC Materials Testing Complete
ODIAT	Dec 04	Tile Impact Testing Complete; RCC Model Correlation Complete; Tile Model Verification Complete
ODIAT	Feb 05	Final RCC Model Verification (Contingency RTF)
ODIAT	TBD	Damage Tolerance Test and Analysis Complete

Space Shuttle Program Return to Flight Actions

Space Shuttle Program Action 15

NASA will identify and implement improvements in problem tracking, in-flight anomaly (IFA) disposition, and anomaly resolution process changes.

BACKGROUND

Bipod ramp foam was released during the launch of STS-112 in October 2002. After the mission, the Space Shuttle Program (SSP) considered this anomaly and directed the External Tank Project to conduct the testing and analysis necessary to understand the cause of bipod foam release and present options to the SSP for resolution. The Program did not hold completion of these activities as a constraint to subsequent Shuttle launches because the interim risk was not judged significant. The *Columbia* accident investigation results clearly disclose the errors in that engineering judgment.

NASA IMPLEMENTATION

NASA will conduct a full review of its anomaly resolution processes with the goal of ensuring appropriate disposition of precursor events in the future. As a part of the safety and mission assurance changes discussed in NASA's response to *Columbia* Accident Investigation Board Recommendation 9.1-1, NASA has transitioned ownership of the Failure Modes and Effects Analysis/Critical Items List and the determination of what constitutes an in-flight anomaly (IFA) to the newly established Independent Technical Authority (ITA). Johnson Space Center (JSC) ITA members are ex-officio members of the Program forums and advisory members of the Program Mission Management Teams. The JSC ITA will remain cognizant of all in-flight issues. Post flight, the Shuttle Program Requirements Control Board and the International Space Station Mission Evaluation Room Manager will remain responsible for the disposition of their respective IFAs. The ITA Program Lead Engineers may make recommendations to the programs regarding any in-flight issues whether dispositioned as IFAs or not. This will ensure an independent review of potentially hazardous issues.

However, the primary responsibility for identifying IFAs remains with the SSP. Accordingly, in support of the return to flight activity, the SSP, supported by all projects and elements, began to identify and implement improvements to the problem tracking, IFA disposition, and anomaly resolution processes. A team is reviewing SSP and other documentation and processes, as well as auditing performance for the past three Shuttle missions. The team concluded that, while *clarification* of the Problem Reporting and Corrective Action (PRACA) System Requirements is needed, the *implementation* of those requirements appears to be the area that has the largest opportunity for improvement. The team identified issues with PRACA implementation that indicate misinterpretations of definitions, resulting in misidentification of problems, and noncompliance with tracking and reporting requirements.

The corrective actions are to

1. Train all SSP elements and support organizations on PRACA requirements and processes. The SSP community is not as aware of the PRACA requirements and processes as they should be to avoid repeating past mistakes.

2. Update NSTS 08126 to clarify the in-flight anomaly (IFA) definition, delete "program" IFA terminology, and add payload IFAs and Mission Operations Directorate (MOD) anomalies to the scope of the document.

3. Update the PRACA nonconformance system (Web PCASS) to include flight software, payload IFAs, and MOD anomalies. These changes will be incorporated in a phased approach. The goal is to have a single nonconformance tracking system.

STATUS

A Change Request (CR) is in work to update NSTS 08126, PRACA System Requirements. NASA and its contractors will provide training as part of this activity to ensure that all SSP elements and support organizations understand the PRACA system and are trained in entering data into PRACA.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
JSC	Aug 04	Approve CR to update NSTS 08126, PRACA Systems Requirements
KSC	Jun 05	Train NASA and contractor personnel on PRACA system requirements, cause codes, and defect codes

Columbia Accident Investigation Board

Observation 10.2-1

Future crewed-vehicle requirements should incorporate the knowledge gained from the *Challenger* and *Columbia* accidents in assessing the feasibility of vehicles that could ensure crew survival even if the vehicle is destroyed.

NASA IMPLEMENTATION

In July 2003, NASA published the Human-Rating Requirements and Guidelines for Space Flight Systems policy document, NPR 8705.2. This document includes a requirement for flight crew survivability through a combination of abort and crew escape capabilities. The requirements in NPR 8705.2 evolved from NASA lessons learned from the Space Shuttle, Space Station, and other human space flight programs, including the lessons from the *Challenger* and *Columbia* accidents. This will be the guiding document for the development of the planned Crew Exploration Vehicle (CEV).

On July 21, 2004, the Space Shuttle Upgrades Program Review Control Board approved the formation of a multidisciplinary team at the NASA Johnson Space Center (JSC) to complete a comprehensive analysis of the two Shuttle accidents for crew survival implications. The team will include personnel from JSC Flight Crew Operations, JSC Mission Operations Directorate, JSC Engineering, Safety and Mission Assurance, the Space Shuttle Program, and Space and Life Sciences Directorate. The team will combine data from both accidents with crew module models and analyses. After completion of the investigation and analysis, the team will issue a formal report documenting lessons learned for enhancing crew survivability in the Space Shuttle and for future human space flight vehicles, such as the CEV.

STATUS

The Space and Life Sciences Directorate is sponsoring a contract with the University Space Research Association and the Biodynamics Research Corporation to perform an assessment of biodynamics from *Columbia* evidence.

FORWARD WORK

In September 2004, the Shuttle Program Requirements Control Board (PRCB) will review the request for funding the multidisciplinary crew survivability team. After funding is approved, the team will complete its analysis within approximately two years. Space Shuttle critical flight safety issues will be reported to the PRCB for disposition. Future crewed-vehicle spacecraft will use the products of the multidisciplinary team to aid in developing the crew safety and survivability requirements.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
JSC Team	Feb 05	Conduct *Challenger* interviews and locate existing data
JSC Team	Mar 05	Assemble existing *Columbia* data and review debris
JSC Team	Sep 05	Analyze data from *Columbia* and *Challenger*
JSC Team	Sep 06	Determine recommendation and write final report

Columbia Accident Investigation Board
Observation 10.5-1

Quality and Engineering review of work documents for STS-114 should be accomplished using statistical sampling to ensure that a representative sample is evaluated and adequate feedback is communicated to resolve documentation problems.

Note: NASA has closed this *Columbia* Accident Investigation Board (CAIB) Observation through the formal Program Requirements Control Board process. The following summary details NASA's response to the CAIB Observation and any additional work NASA intends to perform beyond the CAIB Observation.

BACKGROUND

The Kennedy Space Center (KSC) Processing Review Team conducted a review of the ground processing activities and work documents from all systems for STS-107 and STS-109, and from some systems for Orbiter Major Modification. This review examined approximately 3.9 million work steps and identified 9672 processing and documentation discrepancies resulting in a work step accuracy rate of 99.75%. While this is comparable to our performance in recent years, our goal is to further reduce processing discrepancies; therefore, we initiated a review of STS-114 documentation.

NASA IMPLEMENTATION

NASA has performed a review and systemic analysis of STS-114 work documents from the time of Orbiter Processing Facility roll-in through system integration test of the flight elements in the Vehicle Assembly Building. Pareto analysis of the discrepancies revealed areas where root cause analysis is required.

STATUS

The STS-114 Processing Review Team systemic analysis revealed six Corrective Action recommendations consistent with the technical observations noted in the STS-107/109 review. Teams were formed to determine the root cause and long-term corrective actions. These recommendations were assigned Corrective Action Requests that will be used to track the implementation and effectiveness of the corrective actions. In addition to the remedial actions from the previous review, there were nine new system-specific remedial recommendations. These remedial actions primarily addressed documentation errors, and have been implemented. Quality and Engineering will continue to statistically sample and analyze work documents for all future flows.

The root cause analysis results and Corrective Actions were presented to and approved by the Space Shuttle Program in February 2004.

FORWARD WORK

None.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
KSC	Feb 04 (Completed)	Program Requirements Control Board

Columbia Accident Investigation Board

Observation 10.10-1

Inspection requirements for corrosion due to environmental exposure should first establish corrosion rates for Orbiter-specific environments, materials, and structural configurations. Consider applying Air Force corrosion prevention programs to the Orbiter.

This action also encompasses the action in Recommendation D.a-11, SRB ETA Ring.

BACKGROUND

The External Tank Attach (ETA) rings are located on the Solid Rocket Boosters (SRBs) on the forward end of the aft motor segment (figure O10.10-1). The rings provide the aft attach points for the SRBs to the External Tank (ET). Approximately two minutes after liftoff, the SRBs separate from the Shuttle vehicle.

In late 2002, Marshall Space Flight Center (MSFC) engineers were performing tensile tests on ETA ring web material prior to the launch of STS-107 and discovered the ETA ring material strengths were lower than the design requirement. The ring material was from a previously flown and subsequently scrapped ETA ring representative of current flight inventory material. A one-time waiver was granted for the STS-107 launch based on an evaluation of the structural strength factor of safety requirement for the ring of 1.4 and adequate fracture mechanics safe-life at launch. The most probable cause for the low strength material was an off-nominal heat treatment process. Following SRB retrieval, the STS-107 rings were inspected as part of the normal postflight inspections, and no issues were identified with flight performance. Subsequent testing revealed lower than expected fracture properties; as a result, the scope of the initial investigation of low material strength was expanded to include a fracture assessment of the ETA ring hardware.

NASA IMPLEMENTATION

NASA used a nonlinear analysis method to determine whether the rings met Program strength requirements for a factor of safety of 1.4 or greater. The nonlinear analysis method is a well-established technique employed throughout the aerospace industry that addresses the entire material stress-strain response and more accurately represents the material's ultimate strength capability by allowing load redistribution. Nonlinear analysis demonstrates that all ETA ring hardware meets Program strength requirements.

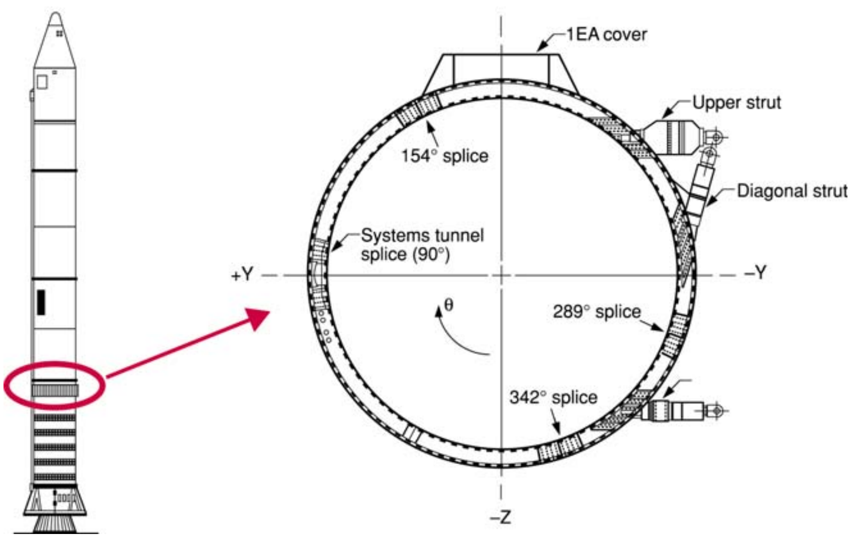


Figure O10.10-1-1. ETA ring location.

In addition to strength analysis, a fracture mechanics analysis will be required to determine the minimum mission life for the rings and to define the necessary inspection interval. Fracture testing on the ETA ring hardware will be performed to determine the appropriate properties for mission-life assessment. NASA will continue to use testing, inspection, and analyses of flight hardware to fully characterize the material for each of the ETA rings in the Shuttle Program inventory. This will provide added assurance that the flight hardware meets program requirements and continues to have an adequate margin for safety above the 1.4 factor of safety requirement.

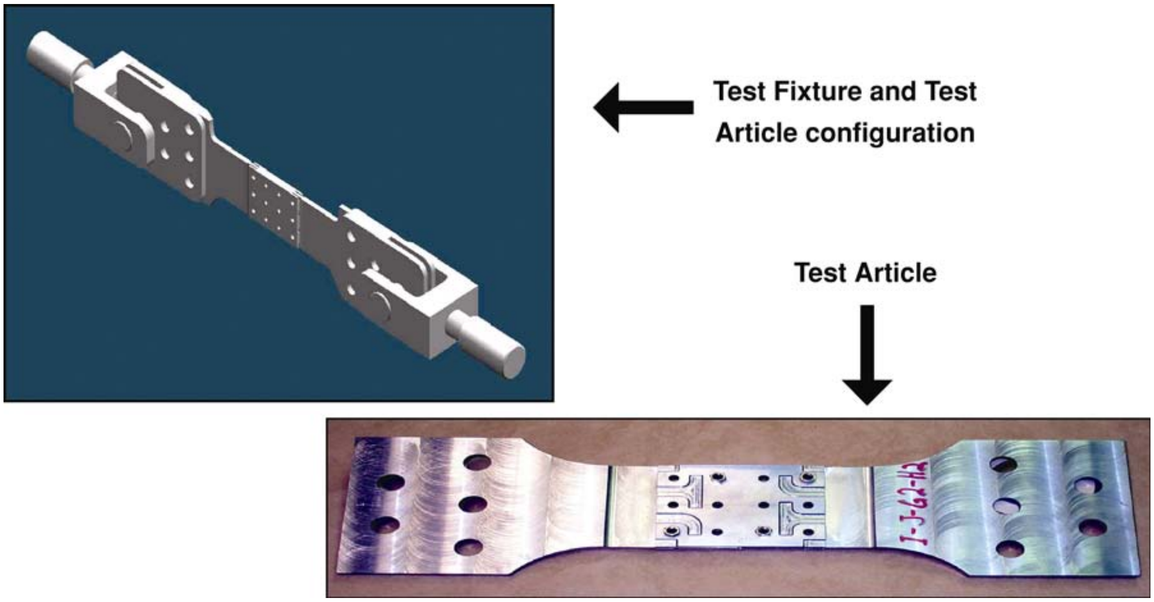


Figure O10.10-1-2. Test articles.

STATUS

The SRB Project has developed and verified by test (figure O10.10-1-2) a nonlinear analysis approach for the 1.4 factor of safety assurance. The hardware materials characterization used in this analysis includes ring web thickness measurements and hardness testing (figure O10.10-1-3) of the splice plates and ring webs.

Serial number 15 and 16 ETA rings exhibited undesirable material variability and are being set aside as the initial candidates for upgrade/replacement. Fracture property testing for the splice plates resulted in unacceptable material properties. Replacement splice plates are being fabricated under controlled processes and lot acceptance testing. Any other ring hardware that exhibits similarly unacceptable material or high variability in the hardness measurements will also be set aside for upgrade or replacement. Fracture Control Plan requirements compliance will be ensured by performing extensive nondestructive inspections to re-baseline all areas of the ETA ring hardware.

Figure O10.10-1-3. Harness testing.

Hardware inspections for the first flight set of ETA rings are complete; there were no reportable problems and all areas of the rings met factor of safety requirements. Safe life requirements are being met using fracture properties derived from extensive ETA ring material testing.

The Space Shuttle Program Requirements Control Board (PRCB) has approved a funding request for procurement of new ETA rings.

FORWARD WORK

The first flight set ETA rings are scheduled for delivery in November 2004, in time to support the fourth Shuttle flight following return to flight. Hardware inspections for each of the remaining ETA rings in the Space Shuttle Program inventory will continue until replacement hardware becomes available.

SCHEDULE

Responsibility	Due Date	Activity/Deliverable
SRB Project	Mar 04 (Completed)	New ring procurement funding approved
SRB Project	Jul 04 (Completed)	*Columbia* Accident Investigation Board observation PRCB action (S064039 MSF-SRB Action 1-1 and 2-1) closure
SRB Project	Aug 04 (Completed)	First flight set ETA rings complete
SRB Project	Nov 04	Delivery of first new ETA ring